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THE ROYAL SOCIETY OF TASMANIA

Edited by V. Mawson

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PAPERS AND PROCEEDINGS OF THE ROYAL SOCIETY OF TASMANIA
VOLUME 135

Contents

page

JAGO, J.B. & BROWN, A.V. — Late Middle Cambrian trilobites from Trial Ridge, southwestern Tasmania 1

KIERNAN, K. — Late Holocene landscape evolution in the Dazzler Range: New evidence 15

BRAY, R.A. & CRIBB, T.H. — *Postlepidapedon quintum* n. sp. (Digenea: Lepocreadiidae) from the bastard trumpeter *Latridopsis forsteri* (Perciformes: Latridae) off the coast of northern Tasmania 21

LOCKHART, S.J. & RITZ, D.A. — Preliminary observations of the feeding periodicity and selectivity of the introduced seastar, *Asterias amurensis* (Lütken), in Tasmania, Australia 25

LOCKHART, S.J. & RITZ, D.A. — Size selectivity and energy maximisation of the introduced seastar, *Asterias amurensis* (Lütken), in Tasmania, Australia 35

WHINAM, J., CHILCOTT, N. & RUDMAN, T. — Impacts of dieback at Pine Lake, Tasmania 41

SHIMELD, P.W. & COLHOUN, E.A. — *Eucalyptus* spp. pollen transport across Liawenee Moor, on the Central Plateau of Tasmania 51

POTTS, B.M., POTTS, W.C. & KANTVILAS, G. — The Miena cider gum, *Eucalyptus gunnii* subsp. *divaricata* (Myrtaceae): a taxon in rapid decline 57

EVERARD, J.L. — Intrusive relationships of granite and dolerite at Lagunta Creek, Freycinet Peninsula 63

Guide for authors 75

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TASMANIA

UNIVERSITY OF TASMANIA

LATE MIDDLE CAMBRIAN TRILOBITES FROM TRIAL RIDGE, SOUTHWESTERN TASMANIA

by J.B. Jago & A.V. Brown

(with one table, one text-figure and three plates)

JAGO, J.B. & BROWN, A.V., 2001 (31:xii): Late Middle Cambrian trilobites from Trial Ridge, southwestern Tasmania. *Pap. Proc. R. Soc. Tasm.* 135: 1–14. ISSN 0080–4703. School of Geoscience, Minerals and Civil Engineering, University of South Australia, Australia 5095 (JBJ); Mineral Resources Tasmania, PO Box 56, Rosny Park, Tasmania, Australia 7018 (AVB).

The first Middle Cambrian trilobites to be described from southwestern Tasmania come from two localities within siltstone in the Trial Ridge area on the HUNTLEY 1:50 000 sheet. Sixteen trilobite taxa are described. The 11 agnostoid species include one new species, *Hypagnostus trali. Lisogoragnostus* is recorded for the first time in Tasmania. The faunas of both localities are of a very similar late Middle Cambrian age, probably high in the *Lejopyge laevigata* Zone on the northern Australian biostratigraphic scale. One fauna is dominated by complete specimens of *Goniagnostus nathorsti* but has very few polymeroids. In the other fauna, there are no complete agnostoids, *G. nathorsti* is absent, and the most common trilobite is a member of the Proasaphiscidae, thus suggesting that the former fauna is of deeper water origin than the latter

Key Words: Middle Cambrian, trilobites, Trial Ridge, southwestern Tasmania.

INTRODUCTION

During the mapping of the *HUNTLEY 1:50 000 Geological Atlas Map Sheet* (Brown *et al.* 1982) new fossil faunas were found in two localities on Trial Ridge. The southern locality (no.1, fig.1), yielded a fauna with abundant agnostoid trilobites, numerous phosphatic brachiopods as well as polymeroids and trilobite tracks. The northern locality (no.2, fig.1) contains a similar but more restricted fauna. The trilobites described in this paper allow their horizon to be dated as late Middle Cambrian, the first of that age to be described from southwestern Tasmania.

Geological Setting

The term "Trial Ridge Beds" was introduced by Corbett (1970) for the succession of sedimentary rocks on Trial Ridge. In the course of mapping the Huntley Quadrangle the sequence on Trial Ridge was re-mapped in greater detail than previously, allowing the rocks within the area to be subdivided into three members. The lowest member (Cml, fig.1) comprises thickly bedded, siliceous, granule to cobble conglomerate and siliceous sandstone. The fossiliferous middle member (Cmm, fig.1) consists of thinly and monotonously interbedded light to dark-grey sandstone and siltstone. Some siltstone units contain abundant muscovite whereas, in other places, siltstone beds contain a sand-grade component. Most of the siltstone beds contain multiple truncated cross-bedding, with some of the interbedded sandstone units having silt-grade basal flame structures. The highest member (Cmh, fig.1) consists of an irregularly interbedded sequence of granule to cobble conglomerate, siliceous pebbly sandstone and siltstone. A detailed description of this succession is contained in Brown *et al.* (1989: 40–45).

Composition and Age of the Faunas

Locality 1 contains the following agnostoid trilobites: *Goniagnostus nathorsti* (Brøgger), *Lejopyge laevigata* (Dalman), *Hypagnostus trali* sp. nov., *Lisogoragnostus* sp., *Oidalagnostus changi* Lu, *Clavagnostus* cf. *repandus* (Westergård), *Glaberagnostus* sp., *Valenagnostus* sp. and Agnostoid gen. et sp. indet. Polymeroid trilobites present are *Amphoton* sp. and Papyriaspididae gen. et sp. indet. Trace fossils, probably formed by polymeroid trilobites, are also present.

The following agnostoid trilobites are present at Locality 2: *Lejopyge laevigata* (Dalman), *Hypagnostus trali* sp. nov., *H. brevifrons* (Angelin), *Ammagnostus laiwuensis* (Lorenz), *Oidalagnostus changi* Lu and Agnostoid gen. et sp. indet. Polymeroid trilobites present are *Fuchouia* sp., *Bathyuriscus(?)* sp. and Proasaphiscidae gen. et sp. indet.

The overlap in the faunal compositions suggests that the two faunas are of similar, if not identical, age. The combination of *Lejopyge laevigata, Goniagnostus nathorsti, Hypagnostus brevifrons, Ammagnostus laiwuensis, Clavagnostus* cf. *repandus* and *Oidalagnostus changi* suggests correlation with the *L. laevigata* Zone on the northern Australian biostratigraphic scale. *Amphoton* and *Fuchouia* are well-known late Middle Cambrian genera from China and Australia. The specimens described herein as Proasaphiscidae gen. et sp. indet. belong in a genus known from several localities elsewhere in Tasmania. These include Native Track Tier and St Valentines Peak (see Laurie *et al.*, 1995, for details of these localities), where the faunas are both of very late Middle Cambrian age (Bao 1995). The combination of the above species suggests an age high in the *L. laevigata* Zone on the northern Australian biostratigraphic scale or near the boundary of the *L. laevigata* and *Proagnostus bulbus* Zones of the late Middle Cambrian of China (Peng & Robison 2000).

The composition of the agnostoid component of both localities (table 1) shows that, while there are similarities in the composition of the faunas from the two localities, there

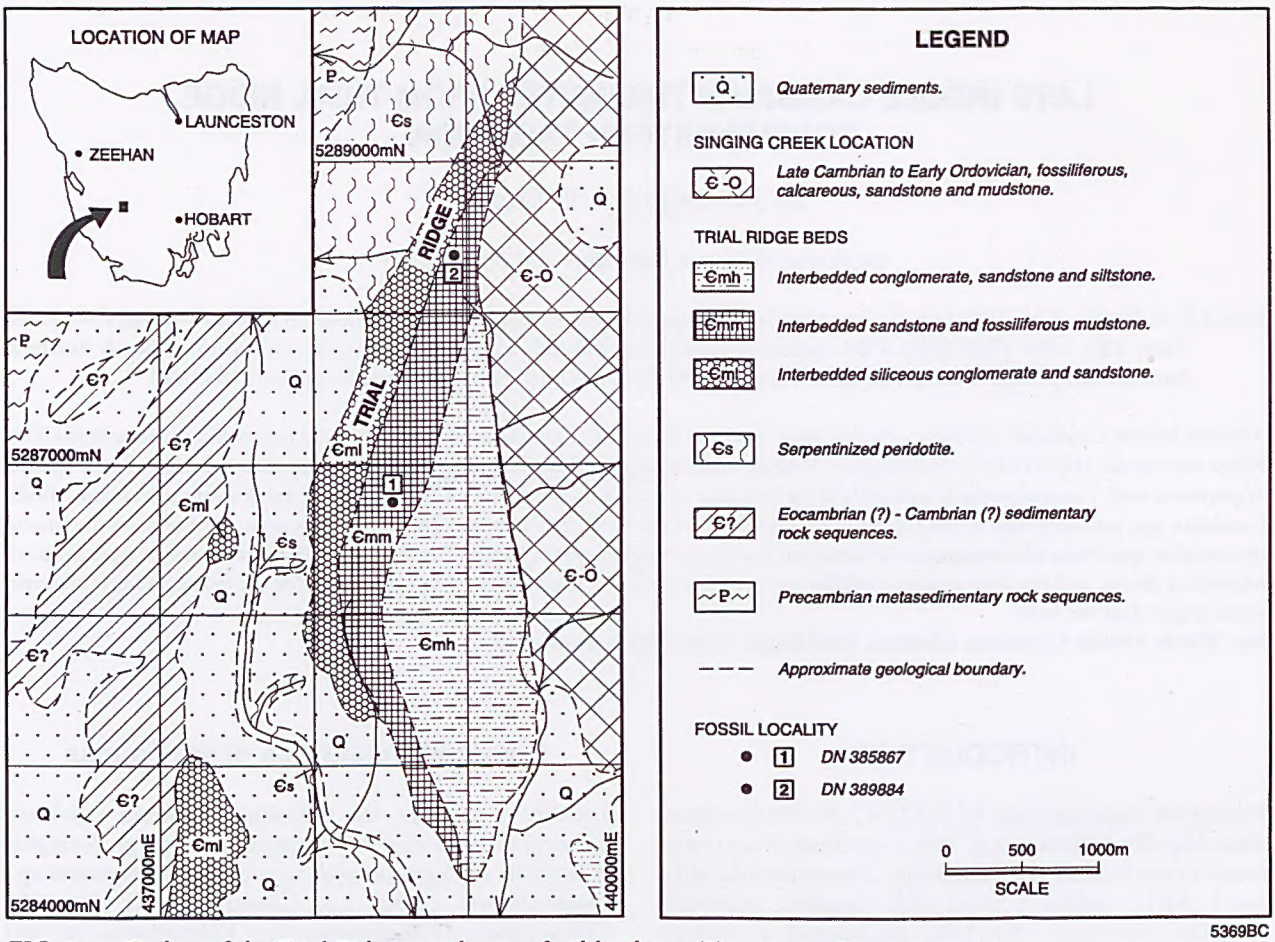


FIG. 1 — Geology of the Trial Ridge area showing fossil localities: (1) southern, (2) northern.

are also some differences. At Locality 1, 59.77% of the known agnostoid cephala and pygidia are found in complete specimens (table 1); *Goniagnostus nathorsti* makes up 67.82% of the agnostoid fauna and only three polymeroid specimens are known.

In contrast to Locality 1, there are no known complete agnostoids from Locality 2, *G. nathorsti* is not present, and polymeroid trilobites make up about 50% of the trilobite fauna. Of the polymeroids, Proasaphiscidae gen. et sp. indet. is the most common trilobite at Locality 2. As noted above, this species is also common in faunas of similar age at Native Track Tier and St Valentines Peak in northern Tasmania. The abundance of complete agnostoids, particularly *G. nathorsti*, at Locality 1 and the absence of *G. nathorsti* and the presence of abundant Proasaphiscidae gen. et sp. indet. at Locality 2 all suggest that the faunas of Localities 1 and 2 respectively fit into Faunas 2 and 3 of Jago (1973), with the Locality 1 fauna being a deeper water fauna than that of Locality 2.

SYSTEMATIC PALAEONTOLOGY

All specimens described occur as internal and external moulds in weathered siltstone. For description, silicone rubber casts of the external moulds were prepared and then photographed after whitening with magnesium oxide. The terminology used for agnostoid trilobites is essentially that of Shergold *et al.* (1990). Specimens are housed in the collection of the School of Earth Sciences, University of Tasmania.

DESCRIPTIONS

Order AGNOSTIDA Salter, 1864
Superfamily AGNOSTOIDEA M'Coy, 1849
Family PTYCHAGNOSTIDAE Kobayashi, 1939
Genus *Goniagnostus* Howell, 1935b

Synonymy

See Lu & Lin 1989: 97. To this should be added Laurie 1989: 176; Shergold *et al.* 1990: 39; Peng & Robison 2000: 71.

Type species

Agnostus nathorsti Brøgger 1878: 68, pl. 5, fig. 1.

Remarks

The generic and subgeneric classification of *Ptychagnostus*, *Goniagnostus* and related taxa has long been problematic (e.g. Öpik 1961, 1979, Robison 1964, 1982, 1984, Laurie 1988, 1989, Westrop *et al.* 1996, Peng & Robison 2000). We follow Peng & Robison in rejecting the subgeneric subdivisions of the genus as proposed by Öpik (1979).

TABLE 1
Analysis of agnostoid trilobites from Trial Ridge*

LOCALITY ONE	Complete specimens	Separate cephala	Separate pygidia	Total no. of specimens	Total cephala and pygidia
Goniagnostus nathorsti	21	10	7	38	59
Lejopyge laevigata	2	2	2	6	8
Hypagnostus trali	1		1	2	3
Lisogoragnostus sp.	1		1	2	3
Oidalagnostus changi		6	1	7	7
Clavagnostus cf. *repandus*			2	2	2
Glaberagnostus sp.	1			1	2
Valenagnostus sp.			2	2	2
Agnostoid gen. et sp. indet.		1		1	1

Total number of cephala and pygidia = 87. Number of cephala and pygidia in complete specimens = 52. Percentage of cephala and pygidia in complete specimens = 59.77%.

LOCALITY TWO	Complete specimens	Separate cephala	Separate pygidia	Total no. of specimens	Total cephala and pygidia
Lejopyge laevigata		3	2	5	5
Hypagnostus trali			1	1	1
H. brevifrons		1		1	1
Ammagnostus laiwuensis		3	1	4	4
Oidalagnostus changi		3	3	6	6
Agnostoid gen. et sp. indet.		4		4	4

* Every available agnostoid cephalon and pygidium is shown on this table. Each individual cephalon and pygidium is counted as one unit; thus a complete agnostoid comprises two units.

Goniagnostus nathorsti (Brøgger, 1878)
Pl. 1A–K

Synonymy
See Peng & Robison (2000: 72)

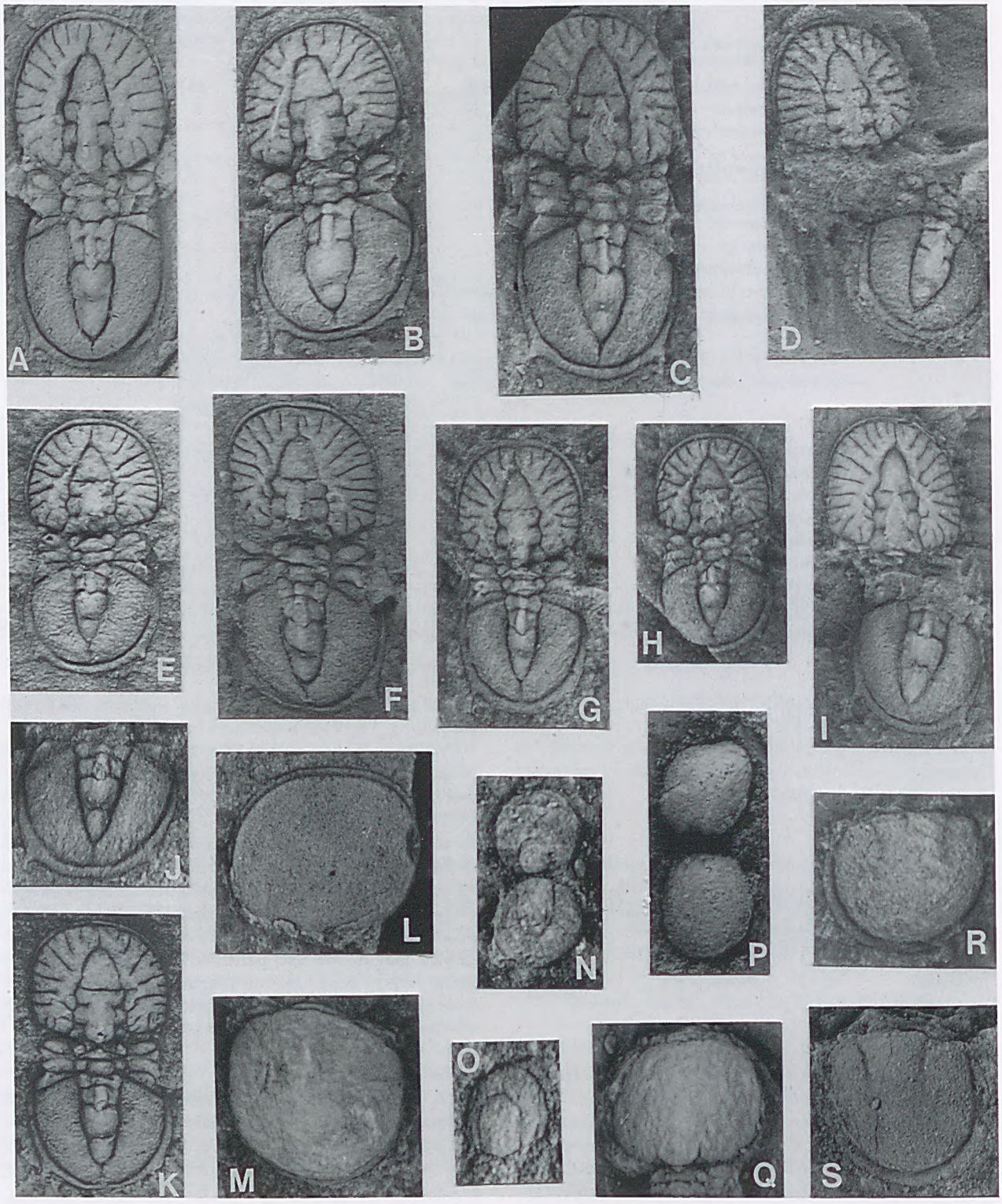
Material
Twenty-one complete, or nearly complete, specimens, plus ten separate cephala and seven separate pygidia. Specimens UTGD 125320a, b, 125321a, b, 125322–125324, 125325a, b, 125326a, b, 125328–125330.

Diagnosis
See Laurie (1989: 177).

Description
Cephalon slightly larger than pygidium, with weakly and finely pustulose surface; cephalon slightly wider than long. Well-developed radial scrobicules. Narrow border; narrow, shallow border furrow. Very short cephalic fulcral spines. Unconstricted acrolobe. Well-developed preglabellar median furrow. Well-defined axial furrows. Glabella length 0.75–0.8 that of cephalon; width about one-third of cephalon. Subtriangular anteroglabella has length about 0.4 that of glabella. F3 well developed; deflected slightly forwards centrally. F1, F2 well developed, extend about one-third of distance into glabella from either side; central part of posteroglabella raised well above lateral parts of glabella. Some specimens (e.g. pl. 1A) have shallow longitudinal furrows that separate the central and lateral parts of the glabella. Central part of glabella increases in height posteriorly. Small subtrapezoidal basal lobes.

Pygidium slightly wider than long. Low pustules on pleural areas coalesce to form a reticulate prosopon. Narrow, shallow border furrow; border widens posteriorly. Short posterolateral spines placed behind axial termination. Large shoulders and facets. Shallow postaxial median furrow shallows posteriorly to border furrow. Pygidial axis outlined by well-developed axial furrows. Axis about 0.7–0.8 length of pygidium; well-developed rosette with node. Axis constricted at M2 and at rosette. F1, F2 well developed. Central part of M1 and particularly M2 separated from lateral parts of axis by shallow longitudinal furrows that are more clearly developed on M2. Central part of M2 extends into a node that continues on to posteroaxis.

Discussion
These specimens fit into *Goniagnostus nathorsti* as discussed by Laurie (1989) and Peng & Robison (2000). *G. nathorsti,* as figured by Westergård (1946: pl. 12, figs 12-16), Öpik (1979: pl. 47, fig.6; pl.60, figs 1–5; pl.61, figs 1, 3–6), Xiang & Zhang (1985: pl. 20, figs 1–3, 6–10), Laurie (1989: fig. 1) and Peng & Robison (2000: fig. 56), shows considerable morphological variation. Variable features include the length of the glabella, the length and width of the pygidial axis and the position and length of the pygidial posterolateral spines. The Trial Ridge specimens show a similar variation, with some of the differences in appearance of the Tasmanian specimens, when compared to the specimens figured in the above papers, being due to the fact that the Trial Ridge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specimens are preserved in a siltstone rather than a limestone. The pygidial spines of the Trial Ridge specimens are longer than most of those shown in the specimens figured by Westergård (1946), Öpik (1979), Xiang & Zhang (1985), Laurie (1989) and Peng & Robison (2000). However, the pygidium figured by Laurie (1989: fig. 1B) has spines of similar length.

The pattern of scrobicules on *G. nathorsti* as figured herein is very similar to that of *G. spiniger* (Laurie 1989: figs 5, 6; Lu & Lin 1989: pl.8, figs 9–12), even down to the small scrobicules arising from the axial furrows just behind F_2. The fact that the only real difference between *spiniger* and *nathorsti* is the length of the cephalic and pygidial spines raises the question as to whether there should be a single species covering specimens normally described under *G. nathorsti* and *G. spiniger*. This is supported when it is noted that the spines in the specimens described from northwestern Tasmania by Jago (1976a) as *Ptychagnostus buckleyi* and placed in synonymy with *spiniger* by Laurie (1989) are intermediate in size between those of *spiniger* illustrated by Laurie and those of *nathorsti* illustrated herein. It could be argued that *spiniger* from Queensland, *buckleyi* from northwestern Tasmania and *nathorsti* from Trial Ridge are simply geographic variants of a single species. However, the difference in the spines of *spiniger* and *nathorsti* is so marked that the writers feel the continued separation into two species is warranted.

Genus *Lejopyge* Hawle & Corda, 1847

Type species

Battus laevigatus Dalman 1828: 136.

Remarks

The concept of *Lejopyge* has been discussed at some length by Daily & Jago (1975), Öpik (1979), Robison (1984, 1994), Laurie (1989), Westrop *et al.* (1996) and Peng & Robison (2000). On the basis of cladistic analysis Robison (1994) placed *Onymagnostus* in synonymy with *Lejopyge*. However, also on the basis of cladistic analysis, Westrop *et al.* (1996) placed *Onymagnostus* in synonymy with *Ptychagnostus*. Peng & Robison (2000) dispute the work of Westrop *et al.* and return *Onymagnostus* to *Lejopyge*. Shergold & Laurie (1997) maintained *Onymagnostus* as a separate genus. A detailed analysis of this matter is outside the scope of this paper, but we would suggest that *Onymagnostus* does not belong in *Lejopyge*. We would prefer to retain *Onymagnostus* as a separate genus.

Lejopyge laevigata (Dalman, 1828)
Pl. 1L–M,P–S; Pl. 2C

Synonymy

See Peng & Robison (2000).

Material

Two poorly preserved complete agnostoids, five poorly preserved cephala and four reasonably well-preserved pygidia are available. Specimens UTGD 125331, 125332a, b, 125335a, b, 125336–125338, 125441.

Remarks

The available cephala are poorly preserved. The very posterior of the glabella is outlined by shallow axial furrows; the basal lobes are very small. The pygidia, which are better preserved, have a narrow, shallow border furrow and a narrow, flat border. The anterior part of the axis is outlined by shallow furrows which fade posteriorly, becoming effaced about the position of the F2 furrow. There is a low node on M2; posterolateral spines are absent.

These specimens are assigned to *Lejopyge* based on the narrow pygidial border, the lack of pygidial spines and the high degree of effacement, suggesting affiliation with either *L. laevigata* or *L. calva*, with the former being preferred.

Family SPINAGNOSTIDAE Howell, 1935a
Genus *Hypagnostus* Jaekel, 1909

Hypagnostus Jaekel 1909: 399; Kobayashi 1939: 122; Lermontova 1940: 129; Westergård 1946: 43 (part); Ivshin 1953: 17; Howell 1959: 184; Öpik 1961:57; Robison 1964: 529 (part); Lu *et al.* 1965: 44; Öpik 1967: 82; Palmer 1968: 31 (part); Jago 1976a: 140 (part); Öpik 1979: 65; Lu & Lin 1989: 105; Shergold *et al.* 1990: 43; Jago & Webers 1992: 106; Westrop *et al.* 1996: 822; Shergold & Laurie 1997: 356; Peng & Robison 2000: 60.

Cotalagnostus Whitehouse 1936: 92; Kobayashi 1939: 129; Lermontova 1940: 129; Westergård 1946: 53; Howell 1959: 184; Robison 1964: 528; Shergold *et al.* 1990: 43; Shergold & Laurie 1997: 356.

PLATE 1

(A–K) Goniagnostus nathorsti *(Brøgger 1878): (A) UTGD125320a complete specimen, holotype, silicone rubber cast of external mould, ×8; (B) UTGD125321b complete specimen, internal mould, ×8; (C) UTGD125322 complete specimen, internal mould, ×5; (D) UTGD125323 complete specimen, internal mould, ×8; (E) UTGD125324 complete specimen, silicone rubber cast of external mould, ×10; (F) UTGD125325a complete specimen, silicone rubber cast of external mould, ×8; (G) UTGD125326b complete specimen, internal mould, ×10; (H) UTGD125327 complete specimen, internal mould, ×10; (I) UTGD125328 disarticulated cephalon and pygidium, internal mould, ×6; (J) UTGD125329 pygidium, internal mould, X6; (K) UTGD125330 complete specimen, silicone rubber cast of external mould, ×8.*

(L–M, P–S) Lejopyge laevigata *(Dalman 1828): (L) UTGD125331 cephalon, internal mould, ×6; (M) UTGD125332b pygidium, internal mould, ×10; (P) UTGD125335b poorly preserved complete specimen, internal mould, ×10; (Q) UTGD125336 cephalon with thoracic segments, internal mould, ×15; (R) UTGD125337 pygidium, internal mould, ×15; (S) UTGD125338 pygidium, internal mould, ×7.*

(N,O) Lisogoragnostus *sp.: (N) UTGD125333 complete specimen, internal mould, ×20; (O) UTGD 125334 partial pygidium, silicone rubber cast of external mould, ×15.*

Specimens figured in L and S come from Locality 2; all others come from Locality 1.

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Type species
Agnostus parvifrons Linnarsson 1869: 82, pl.2, figs 56, 57.

Diagnosis
See Shergold & Laurie (1997: 356), with the amendment that the F3 glabellar furrow may be effaced as may be the posterior parts of the axial furrows of the pygidium.

Discussion
Öpik (1979: 71) stated that although many authors had followed Westergård (1946: 44) in placing *Tomagnostella* in synonymy with *Hypagnostus*, he regarded *Tomagnostella* as a separate genus, a move supported by Robison (1988: 57), Lu & Lin (1989: 108), Shergold *et al.* (1990: 44), Jago & Webers (1992: 106), Shergold & Laurie (1997: 358) and herein.

The generally accepted concept of *Cotalagnostus* is that it is similar to *Hypagnostus* except that the F3 glabella furrow is effaced, as may be the posterior parts of the pygidial axial furrows. Many of the pygidia of *Cotalagnostus lens* and *C. lens claudicus* as illustrated by Westergård 1946 (pls 6, 7) and Hutchinson 1962 (pl. 6) are indistinguishable from those of *Hypagnostus.* Westergård (1946) and Robison (1964) considered *Cotalagnostus* evolved from *Hypagnostus* by effacement of furrows. Westrop *et al.* (1996) concluded that the difference between the two genera, i.e. the presence of a distinct F3 furrow on the cephalon of *Hypagnostus*, was arbitrary and regarded *Cotalagnostus* as a junior synonym of *Hypagnostus.* Shergold & Laurie (1997) maintained the separation of the two genera. Peng & Robison (2000) disputed the placement of *Cotalagnostus* in synonymy with *Hypagnostus,* on the grounds that *Cotalagnostus* is differentiated by the effacement of F3 and the greater effacement of its axial furrows on both the cephalon and pygidium. We accept *Cotalagnostus* as a junior synonym of *Hypagnostus* on the grounds given by Westrop *et al.* (1996) and because, as noted above, it is difficult to distinguish the pygidia of the two genera.

Hypagnostus trali sp. nov.
Pl. 2A, B, D, E

Derivation of name
Anagram of Trial.

Material
The holotype, a complete specimen (UTGD125339), a pygidium with thorax attached (UTGD 125340) and two pygidia (UTGD 125342–43) are assigned to this species.

Holotype
Complete specimen UTGD125339 (Pl. 2A) is selected as holotype.

Diagnosis
Both cephalon and pygidium have unconstricted acrolobes, narrow borders and narrow, shallow border burrows. Posterior part of glabella outlined by shallow axial furrows. Narrow pygidial axis extends almost full length of acrolobe; F1 and F2 effaced. Terminal axial node present.

Description
Complete specimen 3.5 mm long. Acrolobes unconstricted. Cephalon about as wide as long. Narrow, shallow border furrow; narrow convex border. Small basal lobes. Broadly rounded glabellar posterior. Posterior part of glabella outlined by shallow axial furrows which extend almost 0.4 length of cephalon to a position just short of where F3 would be. Pygidium about as wide as long. Narrow, shallow border furrow; narrow, convex border widens posteriorly. Narrow pygidial axis extends almost full length of acrolobe; slight constriction at position of M2. F1, F2 effaced. Terminal axial node present.

Discussion
The pygidial axis of *trali* is narrower and extends further to the posterior than in *H. lens* or the subspecies *H. lens claudicans* (Westergård 1946). The pygidium of *H. confusus* is more effaced than that of *trali,* and where the outline of the axis of *confusus* can be seen (Westergård 1946: pl.7, figs14, 16, 19), it is shorter than that of *trali. H. laevus* is

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PLATE 2

(A,B,D,E) Hypagnostus trali *sp. nov.: (A) UTGD125339 complete specimen, holotype, internal mould, ×10; (B) UTGD125340a pygidium with thorax attached, silcone rubber cast of external mould, ×12; (D) UTGD125342 small pygidium, silicone rubber cast of external mould, ×20; (E) UTGD125343 pygidium, internal mould, ×7.*

(C) Lejopyge laevigata *(Dalman 1828). UTGD125341 pygidium and thoracic segments, silicone rubber cast of external mould, ×10.*

(F,I,J,M–P) Oidalagnostus changi *Lu 1964: (F) UTGD125344 cephalon internal mould, ×8; (I) UTGD125347 cephalon, internal mould, ×6; (J) UTGD125348 pygidium and thoracic segments, internal mould, ×7; (M) UTGD125351 pygidium, internal mould, ×5; (N) UTGD125352 cephalon, internal mould, ×10; (O) UTGD125353 cephalon, internal mould, ×8; (P) UTGD125354 cephalon, silicone rubber cast of external mould, ×10.*

(G,K,L) Ammagnostus laiwuensis *(Lorenz 1906): (G) UTGD125345 cephalon, internal mould, ×5; (K) UTGD125349 pygidium, internal mould, ×6; (L) UTGD 125350 cephalon, internal mould.*

(H) Hypagnostus brevifrons *(Angelin 1851) UTGD125346 cephalon and thoracic segments, internal mould, ×8.*

(Q) Glaberagnostus *sp. UTGD125355b complete specimen, internal mould, ×6.*

(R) Valenagnostus *sp. UTGD125356 partial pygidium, internal mould, ×15.*

(S) Agnostoid gen. et sp. indet. UTGD125357 cephalon, internal mould, ×15.

(T, U) Clavagnostus *cf.* repandus *(Westergård in Holm & Westergård 1930): (T) UTGD125358 partial pygidium, internal mould, ×8; UTGD125359 pygidium, internal mould, ×10.*

(V) Bathyuriscus *(?) sp. UTGD125360 partial cranidium, internal mould, ×10.*

Specimens figured in A–D, I,J, N–R, T and U come from Locality 1; those figured in E–H, K–M, S and V come from Locality 2.

much more effaced than *trali* (Robison 1964: pl.80, figs 17–28). The pygididial axis of *Cotalagnostus* sp.1 of Egorova *et al.* (1982: pl.14, fig. 14) extends to the posterior of the acrolobe as in *trali* but is wider than that of *trali*. The pygidium of *trali* is similar to that of *H. hippalus* Öpik 1961; however, the cephalon of *hippalus* is quite different.

Hypagnostus brevifrons (Angelin, 1851)
Pl. 2H

Synonymy
See Peng & Robison (2000).

Material
One cephalon with attached thoracic segments (UTGD 125346).

Remarks
As noted by Peng & Robison (2000) and other authors, cephala of *H. brevifrons* and *H. parvifrons* are difficult to distinguish. However, when compared with previously illustrated material, this cephalon appears to fit better into *H. brevifrons.*

Genus *Lisogoragnostus* Rozova in Lisogor, Rozov & Rozova, 1988

Synonymy
See Peng & Robison (2000).

Type species
Lisogoragnostus kalisae Rozova in Lisogor *et al.* (1988: 64, pl. 5, fig. 9).

Diagnosis
See Peng & Robison (2000: 64) with the amendment that the pygidium may have a narrow border.

Remarks
Peng & Robison (2000) discussed the genus comprehensively. The pygidium described by Jago (1976a: pl. 26, fig. 15) as Agnostid, gen. et sp. indet. no. 1 figured from St Valentines Peak, Tasmania, should be included in *Lisogoragnostus.* The explanation for plate 26, figure 15 in Jago (1976a) is incorrect in that it states that the specimen is Agnostid, gen. et sp. indet. no. 2.

Lisogoragnostus sp.
Pl. 1N,O

Material
One almost complete specimen (UTGD 125333) and a partial pygidium (UTGD 125334). Neither specimen is well preserved.

Description
Both available specimens small. Complete specimen (pl. 1N) length of 1.5 mm. Acrolobes unconstricted. Cephalon about as wide as long. Very narrow, shallow border furrow; very narrow border. Very small basal lobes. Shallow axial furrow effaced forwards of F3. F3 very shallow; concave anteriorly. Posteroglabella has length about 0.4–0.45 of glabella. Pygidium about as wide as long. Narrow, shallow border furrow; narrow, flat border. Narrow, shallow axial furrow. Axis has length about 0.6–0.65 and width about 0.5 of pygidium. Axis parallel-sided for about 0.75 of length from where it narrows to angulate posterior. F1, F2 effaced. Smooth pleural fields.

Remarks
These specimens differ from previously described species of *Lisogoragnostus* by the presence of a distinct pygidial border. However, the preservation is not good enough to justify the erection of a new species. The Trial Ridge specimens are probably closest to *L. hybus* Peng & Robison (2000: fig.47). However, the cephalon of *L. hybus* is more elongated than the Trial Ridge specimens. The pygidial axis of the Trial Ridge species appears to be angulate in a manner similar to the pygidia described and figured by Rasetti (1967: 38, pl. 10, figs 22–26) as Agnostida, pygidium no. 1, which belong in *Lisogoragnostus* (Peng & Robison 2000). However, preservation of our specimens makes it difficult to be certain about this matter. The anteroaxis of the Trial Ridge specimens is more parallel-sided than in the specimen of *Lisogoragnostus* illustrated by Jago (1976a: pl. 26, fig. 15) as Agnostid gen. et sp. indet. no. 1.

Family AMMAGNOSTUS Öpik, 1967
Genus *Ammagnostus* Öpik, 1967

Synonymy
See Peng & Robison (2000: 25).

Type species
Ammagnostus psammius Öpik 1967: 139, pl. 55, fig. 3; pl. 66, figs 1–4; text fig. 40.

Diagnosis
See Peng &Robison (2000: 25).

Ammagnostus laiwuensis (Lorenz, 1906)
Pl. 2G, K, L

Synonymy
See Peng & Robison (2000: 27).

Material
Three cephala and one pygidium. Specimens UTGD 125345, 125349, 125350.

Diagnosis
See Peng & Robison (2000: 29).

Remarks
These specimens fit *Peronopsis ekip* of Jago (1976a), which was placed in synonymy with *Ammagnostus laiwuensis* (Lorenz, 1906) by Peng & Robison (2000). This synonymy is accepted herein.

Family DIPLAGNOSTIDAE Whitehouse, 1936
Subfamily OIDALAGNOSTINAE Öpik, 1967
Genus *Oidalagnostus* Westergård, 1946

Synonymy
See Peng & Robison (2000).

Type species
Oidalagnostus trispinifer Westergård (1946: 65, pl. 9, figs 4–7).

Diagnosis
See Peng & Robison (2000).

Discussion
Robison (1988: 37) discussed *Oidalagnostus* and related genera in some detail and concluded that *Ovalagnostus* Lu 1974 (type species, *O. changi* Lu *in* Lu *et al.* 1974) and *Tasagnostus* Jago 1976 (type species, *T. debori*) are junior synonyms of *Oidalagnostus* Westergård 1946. Lu & Lin (1989: 81) placed *Tasagnostus* in synonymy with *Ovalagnostus,* which they retained as a separate genus from *Oidalagnostus.* Peng & Robison (2000) included *Ovalagnostus* as a junior synonym of *Oidalagnostus,* as did Shergold *et al.* (1990), Shergold & Laurie (1997) and the present authors. Peng & Robison (2000) place *Tasagnostus compani* of Jago (1976a) questionably in synonymy with *Oidalagnostus changi.* Certainly *compani* and *changi* are quite close and belong in the same genus, *Oidalagnostus,* but better specimens of both species are required before a final assessment is made. Peng & Robison (2000) included *Tasagnostus* as a junior synonym of *Diplagnostus.* However, the two genera are clearly differentated on the basis of the structure of the pygidial axis and the glabellar anterior. Rushton (1978: 264) pointed out that genera such as *Oidalagnostus, Tasagnostus, Cristagnostus, Oedorhachis, Linguagnostus* and *Dolichagnostus* are best distinguished in the features of the pygidial axis.

Shergold *et al.* (1990) placed *Tasagnostus* in the Diplagnostinae along with *Diplagnostus, Baltagnostus, Dolichagnostus, Linguagnostus* and *Oedorhachis,* with *Iniospheniscus* being included questionably in the Diplagnostinae. They suggested that *Diplagnostus, Linguagnostus, Dolichagnostus* and *Tasagnostus* fit into a tight morphological group characterised by a zonate pygidium in combination with an axiolobate or only slightly modified axiolobate condition, frequently with a transverse depression on the anterior of the posterior pygidial lobe and an often sulcate anterior glabellar lobe. Shergold & Laurie (1997) added *Acadagnostus* to the Diplagnostinae.

Shergold *et al.* (1990) and Shergold & Laurie (1997) placed *Oidalagnostus,* along with *Cristagnostus,* in the Oidalagnostinae and characterised the subfamily as having a zonate pygidium, but with a gap in the pygidial collar. They stated that the anteroaxis of the pygidium comprises three segments, that the posterior lobe is subquadrate and extends to the pygidial collar, and that a third, centrally placed marginal spine is present. They suggested that the major features in the phylogeny of *Oidalagnostus* and *Cristagnostus* are the separation of the anterior portion of the posterior lobe of the axis as the third segment of the anteroaxis and the presence of lateral bosses as appendages of this third segment.

As revised above, the only two species of *Tasagnostus* are *T. debori* Jago 1976a and *Tasagnostus* sp. Jago 1976b (pl. 2, fig.18). It is possible that *Tasagnostus* is ancestral to *Oidalagnostus,* with the best known species, *T. debori,* occurring in either the *L. laevigata* I or II Zones on the northern Australian biochronological scale. *O. compani* from St Valentines Peak, Tasmania, is from the *L. laevigata* III Zone or the *Damesella torosa-Ascionepea janitrix* Zone. However, in Queensland *Oidalagnostus* ranges from the *L. laevigata* II Zone through to the lower part of the *Acmarhachis quasivespa* Zone (Öpik 1967: table 4). Öpik (1967: 134) suggested that *O. trispinifer* is found in the *Glyptagnostus stolidotus* Zone of Tasmania. However, to the best of the authors' knowledge, the youngest known *Oidalagnostus* from Tasmania is from the Brewery Junction Formation at Dundas, where it is in either the *Erediaspis eretes* or *Acmarhachis quasivespa* Zone (Jago 1972).

Oidalagnostus changi Lu, 1964
Pl. 2F, I, J, M–P

Synonymy
See Peng & Robison (2000: 56).

Material
Nine cranidia and four pygidia, three of which have attached thoracic segments. Illustrated specimens UTGD 125344, 125347–125348, 125351–125354.

Diagnosis
See Peng & Robison (2000: 57).

Remarks
These specimens are similar to *Oidalagnostus changi* as illustrated by Peng & Robison (2000: fig. 43). The cranidia show some variation. The anterior margin may show a distinct anterior angularity (pl. 2O), may be quite smooth (pl. 2I) or have a slight angularity (pl. 2F, N). The depth of the transverse glabellar furrow is variable, as is the shape of the glabellar posterior. In the pygidium the pleural fields are slightly pitted. The collar is separated from the axis by a shallow, narrow furrow; the knobs on the collar are well developed. There is a well-developed furrow between the collar and the pygidial border.

Family CLAVAGNOSTIDAE Howell, 1937
Subfamily CLAVAGNOSTINAE Howell, 1937
Genus *Clavagnostus* Howell, 1937

Type species
Agnostus repandus Westergård in Holm & Westergård, (1930:13, pl.4, figs 11, 12 only).

Diagnosis
See Jago & Daily (1974: 97).

Clavagnostus cf. *repandus* (Westergård *in* Holm & Westergård 1930)
Pl. 2T, U

Material
Two small, poorly preserved pygidia, UTGD 125358–59.

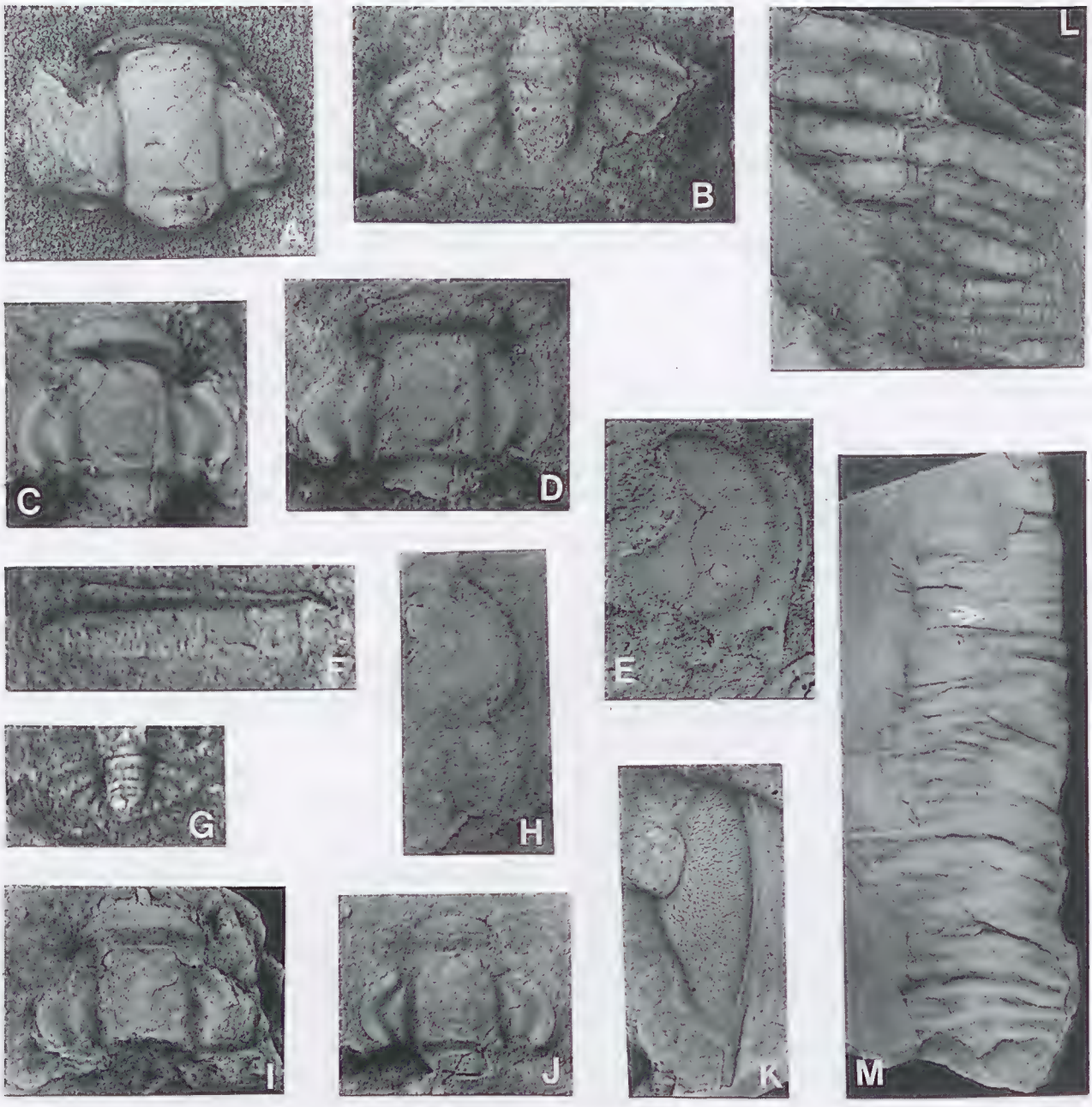

PLATE 3

(A, G) Amphoton *sp.: (A) UTGD125361a cranidium, silicone rubber cast of external mould, ×4; (G) UTGD125367 pygidium, internal mould, ×10.*

(B) Fuchouia *sp. UTGD125362 pygidium, silicone rubber cast of external mould, ×5.*

(C–E, H–J) Proasaphiscidae gen. et sp. indet.: (C) UTGD125363 cranidium, internal mould, ×4; (D) UTGD125364 cranidium, internal mould, ×6; (E) UTGD125365 right librigena, silicone rubber cast of external mould, ×8; (H) UTGD125368 right librigena, internal mould, ×5; (I) UTGD125369 partial cranidium, internal mould, ×3; (J) UTGD125370 cranidium, internal mould, ×6.

(F, K) Papyriaspidae gen. et sp. indet.: (F) UTGD125366 partial thoracic segment, silicone rubber cast of external mould, ×10; (K) UTGD125371 right librigena, silicone rubber cast of external mould, ×5.

(L, M) Trace fossils: (L) UTGD125372 internal mould, ×2; (M) UTGD125373b internal mould, ×1. The arrow points to a small complete specimen of Goniagnostus nathorsti *resting on the tracks.*

Specimens figured in A, F, G, and K–M come from Locality 1; those figured in B–E and H–J come from Locality 2.

Remarks
These pygidia are similar to *C. repandus* as described and illustrated by Westergård (1946), and in particular to the pygidium figured by Westergård (1946: pl.4, fig.22) and refigured by Jago & Daily (1974: 11, fig.4).

Family INCERTAE SEDIS
Genus *Glaberagnostus* Romanenko, 1985

Type species
Glaberagnostus altaicus Romanenko 1985: 57, pl. 5, figs 5–7.

Diagnosis
See Peng & Robison (2000: 90).

Glaberagnostus sp.
Pl. 2Q

Material
One almost complete specimen, UTGD125355a, b.

Description
Specimen length, 7.0 mm. Cephalon almost completely effaced; only very posterior of glabella distinguished. Border appears absent. Position of any glabellar node indeterminate due to preservation. Pygidium with wide border and border furrow; low centrally placed node about 0.2 of distance from anterior to posterior of acrolobe.

Genus *Valenagnostus* Jago, 1976a

Type species
Agnostus nudus Beyrich var. *marginata* Brøgger 1878: 73, pl. 6, fig. 3.

Diagnosis
See Jago (1976a: 142).

Valenagnostus sp.
Pl. 2R

Material
Two small, poorly preserved pygidia. Illustrated specimen, UTGD 125356.

Remarks
The effaced acrolobe, wide pygidial border and suggestion of a terminal axial node suggest affiliation with *Valenagnostus*.

Agnostoid gen. et sp. indet.
Pl. 2S

Material
Five cephala. Illustrated specimen, UTGD 125357.

Description
Narrow border; border furrow of moderate width. Glabella 0.6–0.7 length of cephalon. F1, F2 short, shallow; F3 shallow, straight. Posteroglabella length about 0.7 that of glabella. Glabellar posterior broadly rounded. Shallow preglabellar median furrow extends to anterior border. Small basal lobes confluent behind glabella. Smooth cheeks.

Remarks
These small cephala are not assigned to any particular genus. They may belong in *Agnostus* or a related genus.

Family DOLICHOMETOPIDAE Walcott, 1916
Genus *Amphoton* Lorenz, 1906

Synonymy
See Zhang & Jell (1987: 62).

Type species
Amphoton steinmanni Lorenz (1906: 89, pl. 4, figs 15–17).

Amphoton sp.
Pl. 3A,G

Material
One well-preserved cranidium is available both as the internal and external mould (UTGD 125361a, b); a small pygidium (UTGD 125367) may belong in the same species.

Description
Amphoton with shallow occipital furrow; base of what appears to have been a strong occipital spine preserved. Lateral glabellar furrows entirely effaced. Shallow axial furrows. Glabellar anterior almost straight. Anterior border of moderate width; shallow anterior border furrow. Palpebral areas of fixigenae gently convex. Shallow palpebral furrows. Narrow posterolateral limbs; well-developed posterior border furrow. Pygidial axis stops just short of posterior margin. Axis of four annulations plus terminus; four pairs of pleural furrows. No distinct border.

Remarks
The cranidium shows some similarities with *Amphoton deois*, although the anterior border of *deois* is a little wider, the palpebral areas of the fixed cheeks are a little narrower, and the anterior sections of the facial suture of *deois* do not diverge as much as those of the Trial Ridge form.

The characters of the pygidium, including the absence of a distinct border, suggest affiliation with *Fuchouia* rather than *Amphoton* (e.g. Zhang & Jell 1987: 67). Although it is quite possible that the two specimens described here under *Amphoton* sp. belong in separate species or even separate, but related genera, they are placed together in open nomenclature until more material is obtained.

Genus *Fuchouia* Resser & Endo *in* Kobayashi 1935

Synonymy
See Zhang & Jell (1987: 66).

Type species
Bathyuriscus manchuriensis Walcott (1911: 97, pl. 16, fig. 4).

Fuchouia sp.
Pl. 3B

Material
One pygidium, UTGD 125362

Description
Although posterior of axis is poorly preserved there appear to be four axial annulations plus a terminus. Four pairs of pleural furrows, plus at least two pairs of faintly developed interpleural furrows. Very narrow border.

Remarks
The presence of the interpleural furrows and a very narrow border indicates that this pygidium belongs in *Fuchouia* rather than *Amphoton* (Zhang & Jell 1987: 67).

Genus *Bathyuriscus* Meek, 1873

Type species
Bathyurus(?) haydeni Meek (1873: 484).

Diagnosis
See Robison (1964: 534).

Bathyuriscus (?) sp.
Pl. 2V

Material
One partial cranidium, UTGD125360.

Remarks
This specimen is questionably assigned to *Bathyuriscus* as defined by Robison (1964: 534). In *Bathyuriscus* the glabella expands anteriorly, but this feature is not clear on the available specimen. Robison's diagnosis stated that the palpebral lobes have a length one-third that of the cranidium. However, although a complete cranidium is not available, it is probable that the palpebral lobes of the Tasmanian specimens are considerably longer. When compared with *Bathyuriscus fimbriatus* Robison 1964, *Bathyuriscus (?)* sp. has wider fixigenae.

Family PROASAPHISCIDAE Chang,1963
Proasaphiscidae, gen. et sp. indet.
Pl. 3C–E, H–J

Material
Six partial cranidia and several librigenae. Illustrated specimens, UTGD 125363–125365; 125368–125370.

Description
Large, convex subrectangular glabella about 0.75–0.8 cephalic length and about 0.43 cranidial length. Glabella tapers slightly forwards to a truncated front at anterior border furrow. Deep axial furrows. Lateral glabellar furrows very poorly defined. Shallow occipital furrow; occipital ring narrows abaxially. Long, crescentic palpebral lobes extend from just forwards of occipital furrow to about three-quarters length of glabella. Anterior ends of palpebral lobes close to axial furrows. Wide palpebral furrows. Palpebral areas of fixigenae gently convex. Gently convex anterior border furrow. Anterior sections of facial suture diverge slightly; posterior sections diverge markedly. Wide posterior border furrow. Gently convex librigena with shallow border furrow. Moderately wide border widens posteriorly and extends into long genal spine.

Remarks
These specimens belong to a new genus of the Proasaphiscidae that is also found in other late Middle Cambrian faunas from Tasmania, at Riana, Native Track Tier and St Valentines Peak (Laurie *et al.* 1995). Much better preserved, and more complete specimens, are known from these localities (Bao 1995).

Family PAPYRIASPIDIDAE Whitehouse, 1939
Papyriaspididae gen. et sp. indet.
Pl. 3F, K

Remarks
A single well-preserved partial librigena (UTGD 125371) and a partial thoracic segment (UTGD 125366) may belong in a single genus of the Papyriaspididae. It has a narrow border and part of a well-developed genal spine. A very well-developed and prominent caecal pattern radiates out from the shallow palpebral furrow. The librigena is similar to that figured by Öpik (1961: pl.15, fig. 6) for *Pianaspis sors* (Öpik).

Trace Fossils
Pl. 3L, M

Remarks
Two sets of what appear to be trilobite resting places occur at Locality 1. The larger one (Pl. 3M) has a length of almost 100 mm, while the smaller one (Pl. 3L) has a length of almost 30 mm. Both are incomplete. Given that only two specimens are available, it is difficult to assign these specimens to any particular ichnogenus, but they appear to be related to *Rusophycus*. One of the specimens (Pl. 3M) has a small specimen of *Goniagnostus nathorsti* resting on it.

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(accepted 25 June 2001)

LATE HOLOCENE LANDSCAPE EVOLUTION IN THE DAZZLER RANGE: NEW EVIDENCE

by Kevin Kiernan

(with one table and two text-figures)

KIERNAN, K., 2001 (31:xii): Late Holocene landscape evolution in the Dazzler Range: New evidence. *Pap. Proc. R. Soc. Tasm.* 135: 15–20. ISSN 0080–4703. Forest Practices Board, 30 Patrick Street, Hobart, Tasmania, Australia 7000.

Radiocarbon dating of a wood sample from the upper part of a sequence of coarse fluvial gravels at Branchs Creek has confirmed that accumulation of coarse fluvial gravels continued into the late Mid Holocene, prior to an influx of up to 3 m of sand during the last two millenia. Ongoing erosion at Branchs Creek has revealed that clay previously interpreted as a separate unit beneath the gravels is merely a clay lens and that the gravel/clay sequence is over 3.5 m thick. Investigation of a site at Saxons Creek, at the southern end of the Dazzler Range, has revealed a similar stratigraphy and confirms widespread catchment instability during the Mid to Late Holocene. The upper gravels are again rich in logs and smaller wood fragments, and two samples have returned radiocarbon ages of ~4.1 and 2.2 ka BP. At least 3 m of sand has accumulated since deposition of the gravels ceased, with at least 1 m of sand deposited over the last several centuries. As at Branchs Creek and elsewhere in the Dazzler Range, pronounced incision into alluvial sediments has been triggered by artificial straightening of the Saxons Creek channel.

Key Words: Tasmania, Dazzler Range, radiocarbon dating, fluvial geomorphology, climate change, slope stability, channel stability, land management.

INTRODUCTION

Radiocarbon dating of wood and charcoal from alluvial sediments on the flanks of the Dazzler Range in northern Tasmania (fig. 1) indicated that deposition occurred during the Mid to Late Holocene, 5.2–1.8 kyr BP (Kiernan 1998). Coarse gravels in the earliest deposits were suggested to have been recycled from relict periglacial gravels in response to increased runoff and channel instability, brought about by neoglacial cooling coupled with changes in vegetation structure and associated fire frequency. The aggradation of finer sediment appears to have occurred over the last two millenia. The dating of the gravels rested on a single radiocarbon age of 5220 ± 80 ^{14}C yr BP (Beta 44279) for a wood sample from within the upper part of the gravels at Branchs Creek on the western flanks of the Dazzler Range (Tamar 1:25 000 sheet 8215–690393). The dating of the later sandy alluvial sediments rested on two radiocarbon results from Branchs Creek, and a further radiocarbon date from Massey Creek on the lowermost eastern flanks of the range (8215–795438).

The aims of the present study were (1) to confirm the age of the coarse gravels at Branchs Creek; (2) to revisit the stratigraphy of Branchs Creek in the light of new exposures revealed by ongoing erosion; and (3) to investigate a further sequence of wood-bearing alluvial sediments at Saxons Creek on the southern margin of the Dazzler Range.

NEW EVIDENCE

Branchs Creek

The Branchs Creek section occurs at ~15–25 m altitude at the head of a small alluvial fan that has probably been constructed over an old shoreline of Last Interglacial age. Deep gullying of the alluvial deposits has revealed coarse fluvial gravels buried deeply beneath fluvial sands. Three alluvial units were recognised in the original research at Branchs Creek. Unit Br 1, the uppermost, comprised up to 3 m of sands with weakly developed palaeosols (Kiernan 1998, fig. 2C); unit Br 2 comprised a bed of coarse gravels at least 2 m thick; and unit Br 3 consisted of basal dense clay.

In order to test the earlier dating of the gravels, a further wood sample from Unit Br 2 just upstream from site D at Branchs Creek was collected in July 1998. This sample was obtained from a section 2.9 m high comprising 1.4 m of coarse (Unit Br 2) gravels overlain by 1.5 m of sand (Unit Br 1) (fig. 2, Branchs Ck A). The dated sample was obtained from a large log at 0.8 m depth in the gravels; it returned an age of 4820 ± 70 ^{14}C yr BP (Beta 120239) (table 1).

Further fluvial incision of the sequence since the original study has shown that what was defined as unit Br 3 is, in fact, merely a sandy-clay lens within Unit Br 2, which continues to a depth of at least 0.5 m beneath the lens. The revised stratigraphy presented in figure 2 (Branchs Ck B) supersedes that depicted by Kiernan (1998, fig. 2, column A). The gravel sequence that contains the sand lens is at least 3.5 m thick.

Saxons Creek

Saxons Creek drains a low ridge at the southern end of the Dazzler Range, and discharges ultimately into the southeastern arm of Port Sorell via Franklin Rivulet. Its catchment is slightly larger, lower and less steep than that of Branchs Creek, with which it shares a drainage divide ranging from 520 m to 215 m altitude. As at Branchs Creek and Massey Creek, channel straightening associated with land development for agriculture has increased the erosive capacity of the flow relative to that through the original, unmodified channel, and facilitated pronounced gullying (Kiernan 1999).

An alluvial fan originates at ~110 m altitude and has accumulated on a small plain perched upstream from a structural ridge. The recently eroded gully commences at ~105 m altitude (GR736313), revealing moderately

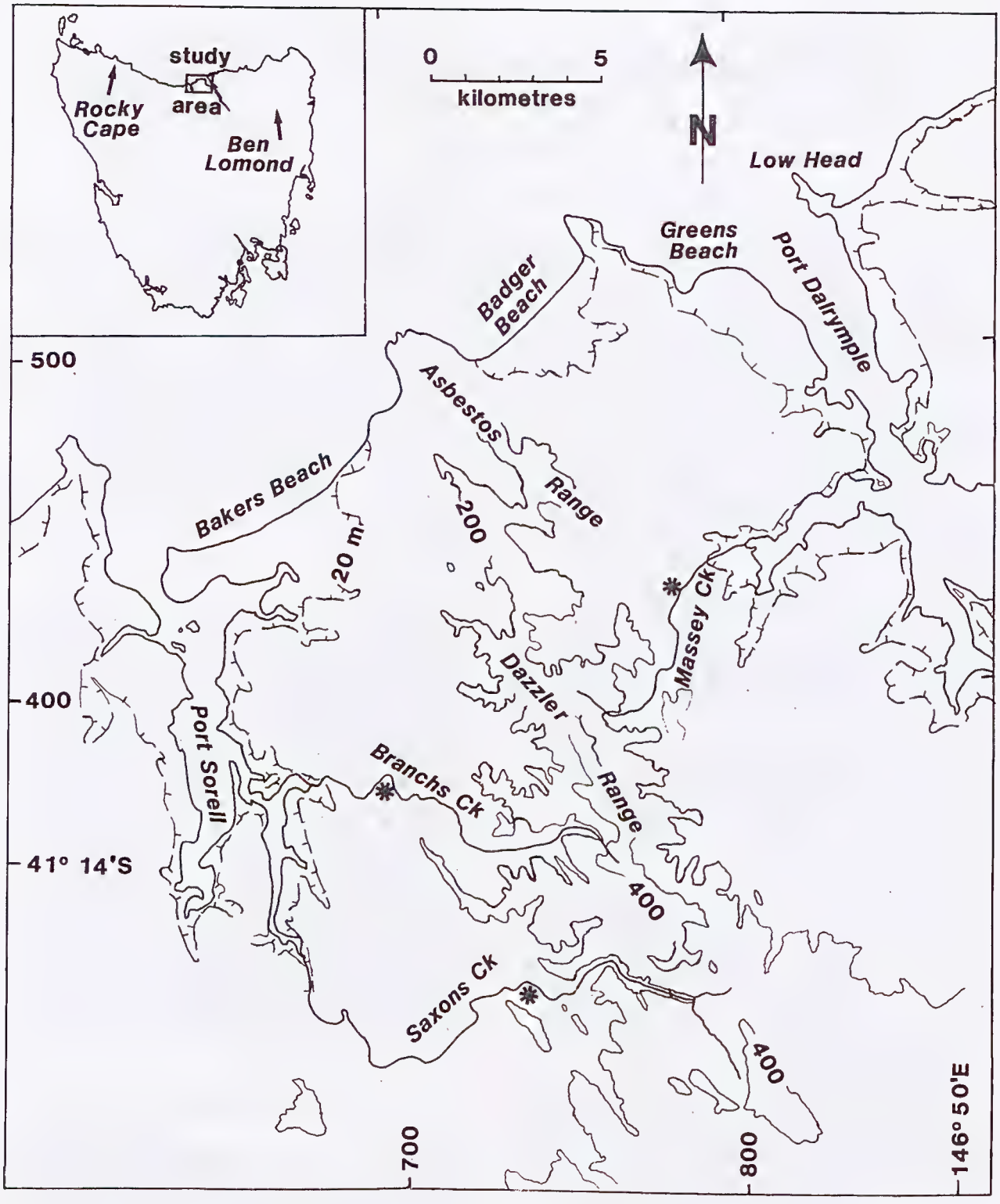

FIG. 1 – Location of the study area. Dated sections are indicated by asterisks.

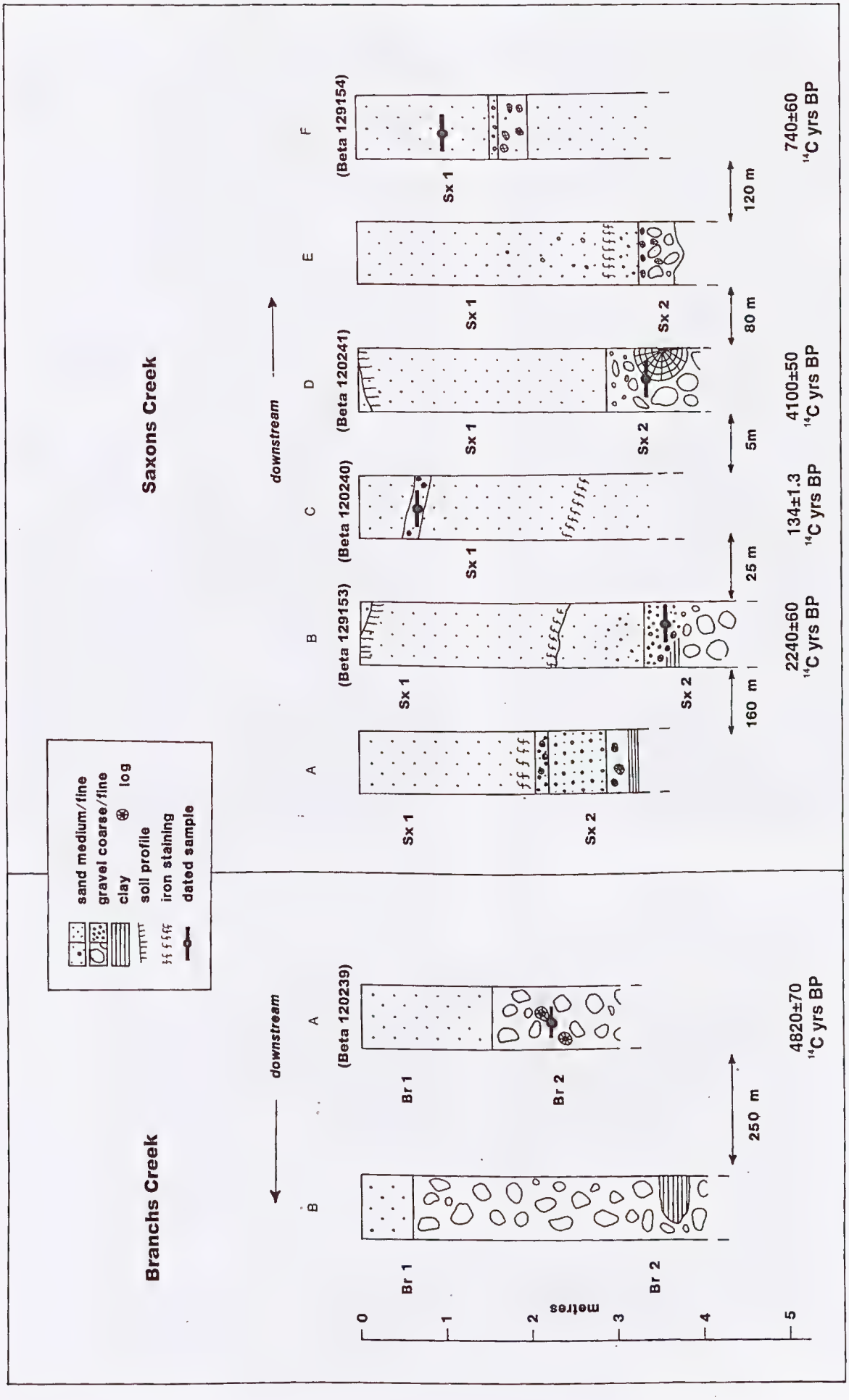

FIG. 2 – Sections through the sediments at Branchs Creek and Saxons Creek. Branchs Creek B supersedes that depicted by Kiernan 1998 (fig. 2, column A), following deeper fluvial incision and exposure of the sequence.

rounded to well-rounded, low-sphericity coarse gravels at least 2 m thick (Unit Sx 2) overlain by at least 3.5 m of sand (Unit Sx 1) (fig. 2, Saxons Ck A–F). The stratigraphy of the Quaternary sediments is essentially identical to that previously described from Branchs Creek and Massey Creek (Kiernan 1998).

On the true left bank of the gully, ~200 m from its origin, ~3.5 m of sand overlies at least 2 m of gravel (Unit Sx 2) that is generally coarse (max. ~0.8 m, mean < 0.4 m) but becomes finer (max. ~0.4 m, mean <0.1 m) within 0.5 m from the top of the unit (fig. 2, Saxons Ck D). A large log nearly 1 m in diameter occurs in the zone of transitional gravel thickness. Radiocarbon dating of a sample from the outer surface of this log produced an age of 4100 ± 50 ^{14}C yr BP (Beta 120241) (table 1). Further upstream, Unit Sx 1 sands ~3 m thick overlie 0.4 m of fine gravels beneath which are coarse gravels (fig. 2, Saxons Ck B). Radiocarbon dating of the outer part of a small log at 0–0.1 m depth in the gravels has given an age of 2240 ± 60 ^{14}C yr BP (Beta 129153).

At both these sites the Unit Sx 1 sand exhibits a mottled zone 0.2–0.3 m thick in its central part. A shallow channel ~1 m deep occurs in the surface of Unit Sx 1 and is floored by 0.3–0.4 m of fine gravels containing small wood fragments. The channel is partly filled by 0.5–0.6 m of sand (fig. 2, Saxons Ck C). Radiocarbon dating of a wood fragment from the gravels on the floor of this channel gave an age of 134 ± 1.3 ^{14}C yr BP (Beta 120240), implying that the wood is modern.

A few hundred metres further downstream, still on the true left, organic materials are more abundant in the Unit Sx 1 sediments (fig. 2, Saxons Ck F). Here, 2 m of medium-fine sand overlies 0.2 m of gritty sand, a woody bed 30–70 mm thick comprising small twigs and branches, and beneath it clayey sand with a blocky structure. The basal clays here are interpreted as stillwater deposits and the woody bed as material washed into a topographic lowpoint. Carbonised wood fragments from 1 m depth in the sand gave a radiocarbon age of 740 ± 60 ^{14}C yr BP (Beta 129154).

DISCUSSION

The radiocarbon result of 4820 ± 70 ^{14}C yr BP (Beta 120239) for the new wood sample from the Unit Br 2 gravels at Branchs Creek strengthens the evidence for significant Mid Holocene instability in this catchment. This result is within two standard deviations of the original age of 5220 ± 80 ^{14}C yr BP (Beta 44279) obtained from the same site. The slightly younger ^{14}C age of 4100 ± 50 yr BP (Beta 120241) from the large log at Saxons Creek is consistent with the caution expressed previously that logs slightly older than the gravel may have become incorporated within it.

The discovery that the clay unit originally defined as Unit Br 3 is merely a lens within the Br 2 gravels rather than a distinct unit means there is no evidence for an earlier phase of only fine sediment aggradation. The possibility that the "basal clay" (Unit M3), previously described from Massey Creek on the eastern side of the range, might also be merely a lens within the gravels that overlie it in the exposure (Kiernan 1998, fig. 2, column G) must also be acknowledged. Hence, there is no compelling evidence for any period of stability between the Last Glacial Maximum (LGM) and deposition of the coarse gravels so that an entirely Holocene age for the gravels cannot be confirmed. However, the radiocarbon ages obtained from the abundant logs and other woody debris within the upper part of the gravels still implies significant catchment instability and gravel mobilisation in the late Mid Holocene.

There are striking similarities between the broad stratigraphic sequence at Saxons Creek and the section previously described from Branchs Creek, although the dating at Saxons Creek raises further questions. The radiocarbon age of 4100 ± 50 ^{14}C yr BP (Beta 120241) obtained from the outer part of a large log in the Unit Sx 2 gravels at Saxons Creek is broadly consistent with the ages obtained from Branchs Creek, though it might suggest gravel deposition occurred slightly later. However, the very much younger age of 2240 ± 60 ^{14}C yr BP (Beta 129153), obtained from another log in a similar stratigraphic context only 20–30 m distant in the same section at Saxons Creek,

TABLE 1
New radiocarbon dates from the Dazzler Range

Sample no.	Laboratory no.	Sample depth (m)	Age (^{14}C yr BP)
Saxons Creek			
SAX-04	Beta 120240	0.6	134±1.3
SAX-12	Beta 129154	1.0	740±60
SAX-03	Beta 129153	3.6	2240±60
SAX-06	Beta 120241	3.5	4100±50
Branchs Creek			
BRA 98/3	Beta 120239	2.2	4820±70

is problematic. This single, appreciably younger age from the finer upper part of these gravels may be explicable by reworking of the gravel surface or by contamination through younger humic acid moving down through the sediment profile, as suggested by the iron mobilisation (fig. 2). However, this date compares with the age of 2580 ± 130 ^{14}C yr BP (Beta 44275) previously obtained on charcoal and wood fragments from 2.2 m depth beneath a thin bed of fine gravel in the sands at Massey Creek, and raises the possibility of ongoing deposition of wood-bearing gravels later than was originally envisaged.

The radiocarbon result of 740 ± 60 ^{14}C yr BP (Beta 129154), obtained from carbonised wood fragments at 1 m depth at site D at Saxons Creek, is significantly younger than the ages obtained from similar depths in the Unit Br 1 sands at Branchs Creek (~1.8 ka BP and ~1.9 ka BP). Some of the differences in age of the coarser and finer alluvial units in different locations throughout the Dazzler Range may be due to intrinsic factors, such as geomorphic responses and response times caused by catchment and topographic differences. The carbonised wood sample from Saxons Creek was obtained towards the distal edge of the alluvial fan, 800 m downstream from the point at which that stream emerges from its valley onto a small, structurally perched plain. The Saxons Creek catchment is slightly larger but less steep than that of Branchs Creek. In contrast, the dated samples from Unit Br 1 at Branchs Creek were obtained from relatively high up the the alluvial fan deposited by that stream where the valley is still relatively narrow (~250 m) and where a small, steep tributary joins the main stream. Overbank flow at Branchs Creek has been confined upstream of the main fan and this, together with the steeper gradient, is likely to have resulted in occasional erosion of upper horizons. The gentler gradient and less confined setting of the Saxons Creek site is more favourable for the accumulation and preservation of flood debris. This interpretation is consistent with the earlier assumption (Kiernan 1998) of ongoing fan accretion well after 1.8 ka BP. At least 3.5 m of sand has accumulated since ~2.2 ka BP, with over 1 m of accretion since 0.7 ka BP. These figures would imply accretion at a mean rate of 1.3–1.6 mm/a if sand deposition were continuous. However, the presence of weakly developed palaeosols within the sands at Branchs Creek (Kiernan 1998, fig. 2C) implies that periods of stability intervened.

The transition from sand accumulation to the deep incision of the previously accumulated sediments occurred well after 740 yr BP. The very straight trajectory of the Saxons Creek channel suggests it has been artificially modified, and gullying subsequent to channel straightening would be consistent with the known triggers of the erosion at Branchs Creek and Massey Creek. The shallow, buried channel in the surface of the sands at Saxons Creek (fig. 2X) is interpreted as a remnant of the natural drainage system that existed on the plain prior to European settlement. The modern ^{14}C age (134 a) from the floor of this channel is consistent with the thesis of relative channel stability prior to European settlement and artificial canalisation of the water flow.

The new evidence from Saxons Creek extends the evidence for widespread catchment instability in the Dazzler Range during and since the late Mid Holocene. Coarse gravels similar to those previously deposited by streams draining the Dazzler Range are no longer being deposited today. While they are similar to gravels that have commonly been attributed to periglacial slope instability, the dating indicates that at least their upper horizons considerably postdate the LGM, when periglacial processes are likely to have been significant on the low Dazzler Range. For this reason, they were previously interpreted as having been reworked from reservoirs of periglacially derived sediment that had stabilised earlier in the Holocene, but were destabilised in the late Mid Holocene (Kiernan 1998). The deeper exposure now accessible at Branchs Creek contradicts the suggestion that the coarse gravels overlie sands, previously interpreted as Early Holocene, hence an entirely Holocene age for the gravels remains unproven.

If the similarity of the stratigraphy observed at Branchs Creek, Massey Creek and Saxon Creek can be taken to imply a phase of slope instability and alluvial sedimentation that affected the entire range, which seems highly probable, then the evidence now available suggests it may be no older than ~4.1 ^{14}C kyr BP. This remains consistent with the earlier suggestion that neoglacial cooling coupled with changes in fire frequency may have been involved. Speleothem evidence from Lynds Cave at Mole Creek, central northern Tasmania, indicates conditions of maximum cold at ~3.8 kyr BP (Goede & Hitchman 1984). Palaeotemperatures calculated from speleothems from Frankombes Cave in the Florentine Valley, south-central Tasmania, suggest temperatures were 2–3°C colder than now at ~4.1 kyr BP and nearly as low on at least four other occasions between 3.8 kyr BP and 3.0 kyr BP (Goede *et al.* 1990). The onset of gravel deposition in the Dazzler Range slightly predates 4.1 kyr BP and it probably terminated before 3.0 kyr BP. Analysis of pollen from sediments at Solomons Jewel Lake in highland central northwestern Tasmania led Dodson (2001) to suggest the main vegetation type did not change over the past 4.0 kyr, but subtle changes occurred in some elements. He suggested sclerophyll vegetation remained unchanged, apart from a reduction in Eucalyptus ~3.5–3.2 kyr BP, but a small decline in rainforest taxa began ~1.7 kyr BP, followed by expansion of Sphaghum from 1.2 kyr BP and *Athrotaxis cupressoides* and Cyperaceae at 0.9–0.8 kyr BP, which may have been associated with cooling.

There is no evidence for any resurgence of glacial activity in Tasmania during the Holocene, consistent with the limited temperature decline that has been suggested and the present height of the theoretical snowline (Kiernan 1991). However, abundant evidence exists in the higher mountains that occur elsewhere in temperate southern latitudes. Some glaciers in the southern Andes may have readvanced from 4.7–3.3 ka BP, >2.5 ka BP, 2.5–1.3 ka BP, and on several occasions during the last 1.2 ka BP (Clapperton 1993). Nested moraines indicate that neoglacial advances in New Zealand diminished only slightly towards the present (Birkeland 1982, Chinn 1996). The culmination of Early Neoglacial Advance in New Zealand is provisionally dated to ~4.6–4.4 kyr BP (Porter 2000).

The Stanley River in western Tasmania appears to have stabilised in its present channel at 3.5–3.2 ka BP, with complete stabilisation in its present channel occurring after this. Nanson *et al.* (1995) interpreted this as being due not to any detectable vegetation change but to a change in climate and a reduction in flow evident from a decline in channel capacity and sediment texture. The new ^{14}C dating evidence from Branchs Creek and Saxon Creek, and analogy with the evidence for recurrent cold phases at broadly equivalent southern latitudes in New Zealand and South

America, support the evidence for catchment instability in the Dazzler Range having been driven by temperature decline, probably coupled with changes in vegetation structure and fire frequency. Since no significant decline in sea level occurred during the Late Holocene cool episodes, the floor of Bass Strait would not have been exposed and, hence, enhanced continentality would not have diminished precipitation. If the forest biomass on slopes was reduced by temperature effects but precipitation did not decline significantly, then enhanced runoff and erosion is likely to have ensued. Alternatively, significant catchment erosion is also likely to have ensued if the redevelopment of the vegetation lagged behind an increase in precipitation.

Hope (1999) suggested human impact may have been the dominant influence on vegetation change over the last 4000 years in island and mainland northwestern Tasmania. He recorded a distinct phase of highly carbonised particle accumulation in organic lagoon sediments from 4000–2500 yr BP at Stockyard Creek on Hunter Island, Bass Strait, associated with increased woody vegetation, that he suggested may correspond with abandonment of the island by Aborigines. Moderate to low charcoal levels thereafter may represent a more variable fire regime. Hope found only moderate levels of burning evident from similar sediments at Sundown Creek, 60 km further south on the west coast of mainland Tasmania, until a general increase in burning coincident with European colonisation. Similarly, Hopf *et al.* (2000) suggested the dominant factors responsible for Mid to Late Holocene vegetation change around Lake St Clair, west-central Tasmania, were reduced precipitation and Aboriginal burning. However, no direct evidence has been found to implicate Aborigines in the catchment instability in the Dazzler Range.

The evidence for deposition of substantial volumes of sediment during the Late Holocene emphasises the metastable condition of the Dazzler Range catchments. The dramatic decline in stability of the Saxons Creek channel following its artificial straightening as part of pasture development mirrors similar problems elsewhere around the flanks of the range and further emphasises the need for a cautious approach to land management in the area.

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POSTLEPIDAPEDON QUINTUM N. SP. (DIGENEA: LEPOCREADIIDAE) FROM THE BASTARD TRUMPETER *LATRIDOPSIS FORSTERI* (PERCIFORMES: LATRIDAE) OFF THE COAST OF NORTHERN TASMANIA

by Rodney A. Bray & Thomas H. Cribb

(with one text figure)

Bray, R.A. & Cribb, T.H., 2001 (31:xii): *Postlepidapedon quintum* n. sp. (Digenea: Lepocreadiidae) from the bastard trumpeter *Latridopsis forsteri* (Perciformes: Latridae) off the coast of northern Tasmania. *Pap. Proc. R. Soc. Tasm.* 135: 21–23. ISSN 0080–4703.
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The new lepocreadiid species, *Postlepidapedon quintum*, is erected for worms recovered from the perciform fish *Latridopsis forsteri* off the coast of northern Tasmania. It is distinguished from its congeners by the vitelline extent and the shape and thickness of the wall of the internal seminal vesicle. A key to the genus *Postlepidapedon* is given. *P. quintum* is likely to be endemic to southern Australia and New Zealand, as is its host.
Key Words: ***Postlepidapedon, Latridopsis,*** **Digenea, Lepocreadiidae, Tasmania.**

INTRODUCTION

Postlepidapedon Zdzitowiecki, 1993 was erected by Zdzitowiecki (1993) to accommodate his species *Neolepidapedon opisthobifurcatus* Zdzitowiecki, 1990 from the gadiform fish *Muraenolepis microps* off South Georgia (Zdzitowiecki 1990). This species had an "Opechona-type" cirrus-sac (as defined by Bray & Gibson 1989), but with an elongate, rather than oval, internal seminal vesicle, and the intestinal bifurcation displaced posteriorly at about the level of the posterior margin of the ventral sucker (Zdzitowiecki 1990; Zdzitowiecki & Cielecka 1997). Bray *et al.* (1997) placed three further species in the genus — *P. secundum* (Durio & Manter, 1968), *P. spissum* Bray, Cribb & Barker, 1997 and *P. uberis* Bray, Cribb & Barker, 1997 — and gave a key to these four species. In this paper we present a description of a further species of *Postlepidapedon.*

We are aware of only two previous records of digeneans from *Latridopsis forsteri*, a perciform teleost endemic to southern Australia and New Zealand (Froese & Pauly 2001). These records are of the opecoelid *Opecoelus tasmanicus* Crowcroft, 1947 from the Hobart fish market, Tasmania (Crowcroft 1947), and the lepocreadiid *Scaphatrema nemadactyli* (Kurochkin & Korotaeva, 1972) from the Great Australian Bight/Tasman Sea area (Kurochkin & Korotaeva 1972).

MATERIALS AND METHODS

Digeneans collected from freshly killed fish were fixed by being pipetted into nearly boiling saline and immediately preserved in formalin or 70% ethanol. Whole-mounts were stained with Mayer's haematoxylin, cleared in methyl salicylate and mounted in Canada balsam. Measurements were made through a drawing tube on an Olympus BH-2 microscope, using a Digicad Plus digitising tablet and Carl Zeiss KS100 software adapted by Imaging Associates, and are quoted in micrometres, averages are in parentheses. The following abbreviations are used: BMNH, the British Museum (Natural History) collection at The Natural History Museum, London, UK; QM, Queensland Museum collection, Brisbane, Australia.

RESULTS

Family Lepocreadiidae Odhner, 1905
Family Lepocreadiinae Odhner, 1905
Genus *Postlepidapedon* Zdzitowiecki, 1993

Postlepidapedon quintum n. sp. (Fig. 1A, B)

Material studied

Ex *Latridopsis forsteri* (Castelnau) (Latridae). Intestine. Off Stanley, Tasmania (40°46'S, 145°20'E, Dec., 1999). Prevalence 75% (six of eight hosts infected). QM holotype G217784, paratypes G217785-217798, BMNH paratypes 2001.6.1.1-8.

Description

Based on 22 whole-mounts. Body with narrow, tapering forebody, wider hindbody, 773–1634 × 237–443 (1088 × 342); width 26–40 (32) % of length (fig. 1A). Tegument spinose; spines becoming scarcer posteriorly, reach to close to posterior extremity. Eye-spot pigment sparse, scattered in forebody, or not seen. Pre-oral lobe short, 1–16 (6). Oral sucker subglobular, subterminal, 90–172 × 91–179 (123 × 132). Ventral sucker rounded, pre-equatorial, 104–205 × 114–218 (152 × 160). Forebody 213–498 (299) long, 24–31 (27) % of length. Sucker-width ratio 1:1.11–1.56 (1.22). Prepharynx short, but distinct, partly in posterior concavity of oral sucker, thick-walled, 10–50 (26) long. Pharynx subglobular, 59–128 × 57–113 (82 × 85). Pharynx to oral sucker width ratio 1:1.20–1.64 (1.55). Oesophagus distinct, 30–87 (54) long. Intestinal bifurcation more or less dorsal to anterior part of ventral sucker. Caeca blind, reach to within 21–117 (53) of posterior extremity.

Testes 2, tandem, oval, entire, contiguous, usually contiguous with ovary, occasionally slightly separated by up to 21; anterior 87–159 × 106–168 (113 × 136), posterior

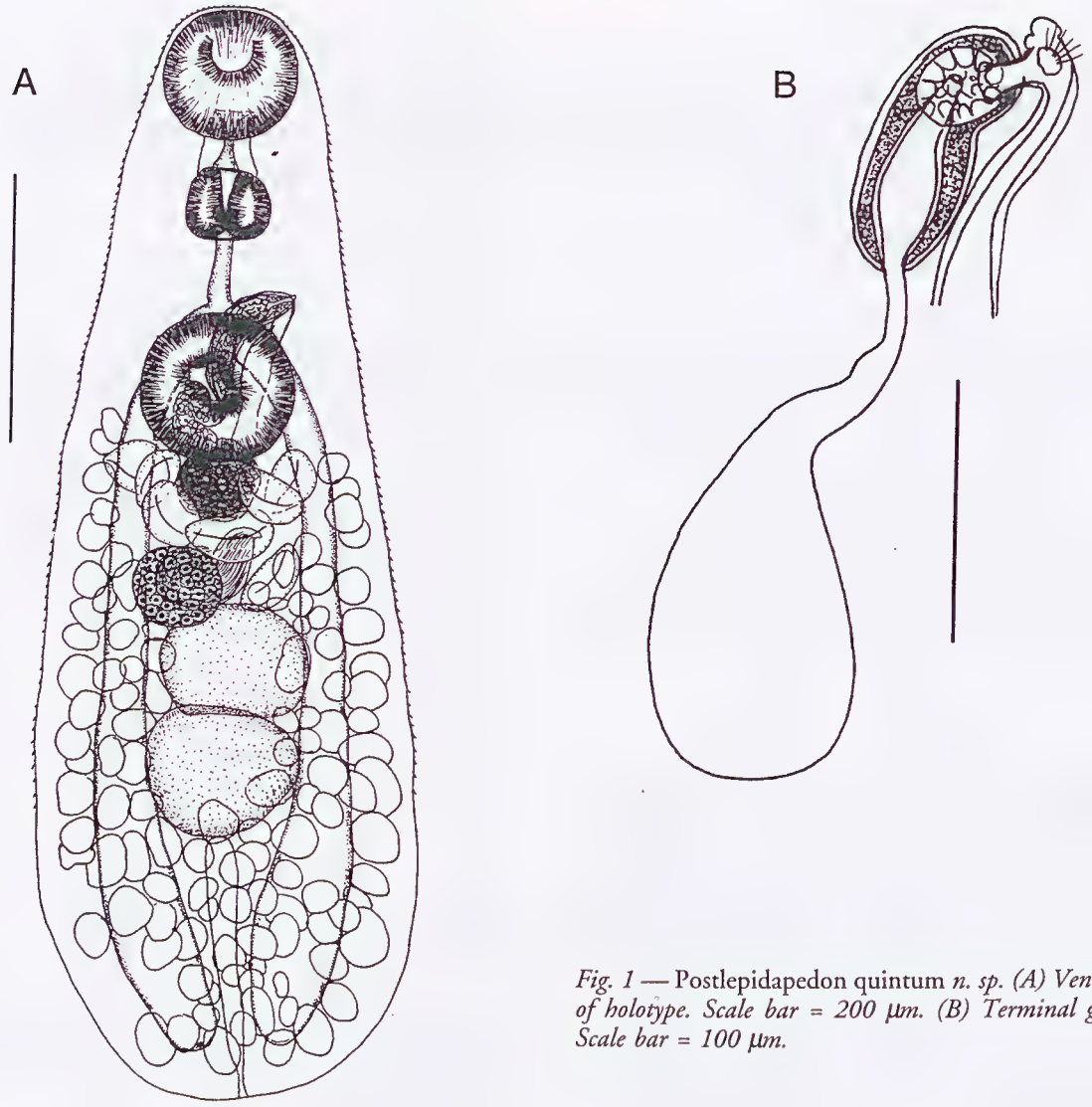

Fig. 1 — Postlepidapedon quintum *n. sp. (A) Ventral view of holotype. Scale bar = 200 μm. (B) Terminal genitalia. Scale bar = 100 μm.*

101–204 × 110–187 (133 × 135). Post-testicular region 161–390 (255) long, 19–27 (23) % of body length. External seminal vesicle saccular, reaches 42–127 (77) into hindbody, 49–140 (87) % of ventral sucker to ovary distance. Cirrus-sac oval, slightly curved, overlaps to about middle of ventral sucker, wall fairly thick, 89–197 × 27–60 (119 × 36) (fig. 1B). Internal seminal vesicle rectilinear, fusiform, fairly thick-walled. Pars prostatica vesicular, subglobular, lined with anuclear cell-like bodies, towards distal end of cirrus-sac. Ejaculatory duct short, wide. Everted cirrus not seen. Genital atrium distinct. Genital pore sinistral, about midway between median line and body margin, just pre-bifurcal in posterior forebody.

Ovary subglobular, entire, usually contiguous with anterior testis, sinistral, 51–140 × 44–125 (83 × 79); 59–128 (90) from ventral sucker. Seminal receptacle canalicular, saccular, mainly dorsal to ovary. Mehlis' gland dorso-median to ovary. Laurer's canal opens dorsally to left caecum at level of posterior part of uterus. Uterus pretesticular, sinistral to ovary and between ovary and about mid-ventral sucker level. Eggs not numerous, tanned, operculate, 59–92 × 24–53 (76 × 40), decrease slightly in size with increase in degree of tanning. Metraterm muscular, commences about mid-ventral sucker level. Vitellarium follicular; fields reach from level of ventral sucker or occasionally just posterior (<15) to posterior extremity; lateral fields lie ventral, lateral and dorsal to caeca, encroaching only slightly over gonads, confluent dorsally and ventrally in post-testicular region.

Excretory pore terminal. Excretory vesicle I-shaped, reaches just to posterior margin of posterior testis.

DISCUSSION

This new species fits comfortably into the small genus *Postlepidapedon* Zdzitowiecki, 1993, which is characterised mainly by the relatively narrow internal seminal vesicle (as opposed to the oval to subglobular internal seminal vesicle found in most lepocreadiines) and the intestinal bifurcation being dorsal to the ventral sucker. Other species of the genus tend to have the intestinal bifurcation at a level relatively further posterior than *P. quintum*. Nevertheless, the five species now recognised are all similar. *P. quintum* and *P. opisthobifurcatum* both have their vitellarium reaching to, or almost to, the ventral sucker, whilst the other three species have their vitellarium restricted to well within the hindbody.

The intestinal bifurcation of *P. quintum* is slightly more anterior than that found in *P. opisthobifurcatum* and the wall of the internal seminal vesicle distinctly thicker. The internal seminal vesicle is more or less rectilinear in *P. quintum*, *P. opisthobifurcatum* and *P. spissum*, whereas it is thin-walled and coiled in *P. uberis* and *P. secundum*.

Postlepidapedon is now known from gadiforms of the families Muraenolepididae and Macrouridae and perciforms of the families Labridae and Latridae. It is restricted to the Southern Hemisphere, i.e. from the waters off Australia, New Caledonia and the Antarctic. *P. quintum* adds a further species to the endemic fauna which make up some 85% of the fauna in the waters of southern and southwestern Australia (Bray & Cribb 2001; Bray *et al.* 1999).

ACKNOWLEDGEMENTS

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(accepted 10 May 2001)

PRELIMINARY OBSERVATIONS OF THE FEEDING PERIODICITY AND SELECTIVITY OF THE INTRODUCED SEASTAR, *ASTERIAS AMURENSIS* (LÜTKEN), IN TASMANIA, AUSTRALIA

by S. J. Lockhart and D.A. Ritz

(with three tables and three text-figures)

LOCKHART, S.J. & RITZ, D.A., 2001 (31:xii): Preliminary observations of the feeding periodicity and selectivity of the introduced seastar, *Asterias amurensis* (Lütken), in Tasmania, Australia. *Pap. Proc. R. Soc. Tasm.* 135: 25–33. ISSN 0080–4703. Department of Ocean Sciences, University of California, Santa Cruz, USA (SJL); and School of Zoology, University of Tasmania, GPO Box 252-5, Hobart, Tasmania, Australia 7001 (DAR).

Field observations of the introduced north Pacific seastar, *Asterias amurensis,* in Tasmania showed that it feeds over the 24-h period with no obvious cycle of activity. Percentage of seastars feeding at any time ranged from 17.2% at 1600 h to 58.2% at 2000 h. Feeding periodicity did not correlate with the time of day or the height of the tide. A significantly higher proportion of juveniles than adult seastars were found to be feeding at any given time. A comparison of prey items found in the stomachs with the availability of prey items in sediments revealed that, in the field, *A. amurensis* selected some prey species and avoided others. A total of 15 species were consumed, with molluscan prey the most important (> 60%) in winter and spring and at the two depths studied (2 m and 5 m). It is concluded that *A. amurensis* is an opportunistic generalist predator but shows a certain degree of specialisation in local populations. All bivalves at the field site were found to be juveniles (most < 5 mm shell length). Whether this is a natural phenomenon or due to the presence of *A. amurensis* cannot be ascertained, as there are no data from these sites prior to the introduction of this seastar. Due to the dominance of juveniles, the resilience of the bivalve community is likely to be low.

Key Words: ***Asterias amurensis*, asteroid, feeding periodicity, introduced species, prey selectivity, Tasmania.**

INTRODUCTION

Asterias amurensis was first collected in southeastern Tasmanian waters in 1986 but was not correctly identified until 1991 (Turner 1992, Buttermore *et al.* 1994, Byrne *et al.* 1997). The asteroid is thought to have been introduced as larvae transported in the ballast waters of ships (Turner 1992, Buttermore *et al.* 1994) from the North Pacific. *A. amurensis,* in its native habitat, is a notorious predator on commercial scallops and a great variety of other benthic invertebrates (Hatanaka & Kosaka 1959) and, thus, is considered a major threat to the native marine fauna of Tasmania. Unfortunately, little is known about the ecology of *A. amurensis,* despite this species being considered a pest even within its natural range.

Seastars are known to exhibit differing feeding intensities with the different seasons, due to (amongst other reasons) external temperature changes and/or internal physiological changes such as those associated with reproduction. At varying times feeding activity can slow or even cease altogether. The variations in asteroid feeding intensity over a 24-h period have been found to be controlled by light (Fenchel 1965, McClintock & Lawrence 1981), tidal variations (Paine 1969, Menge 1972), prey availability (Mori & Matutani 1952, Ribi & Jost 1978, McClintock & Lawrence 1985, Beddingfield & McClintock 1993) or a combination of these.

A predator's selectivity for prey can lead to the obliteration of preferred species populations (Murdoch 1969, McClintock & Lawrence 1985). Predators such as seastars, which exhibit intense prey species selectivity, can have considerable effects upon a number of ecological parameters such as

(1) the distribution of prey species and their competitors (Connell 1961, Landenberger 1968);

(2) community structure and species diversity (Paine 1969, 1976, Ormond *et al.* 1976, Lubchenco & Menge 1978, Menge 1982, Duggins 1983, O'Neill *et al.* 1983, Robles *et al.* 1990);

(3) the age structure (Fukuyama & Oliver 1985) and reproductive tactics of prey populations (Curio 1976 in Annett & Pierotti 1984).

Many important factors are involved in prey choice by predatory seastars (Menge 1971, Dayton *et al.* 1977, Sloan 1980a). These include availability, which is dependent on geographical and local community variability, caloric yield of prey and catchability, including pursuit and handling of prey, which, in turn, is dependent on prey and predator distribution, abundance and behaviour. Landenberger (1968) also lists past feeding experience as another variable affecting prey selectivity. To complicate the situation further, the attraction and/or repulsion of asteroids to various chemical cues can vary over the year (Castilla 1972a,b, Sloan 1980a).

Asteroids are known to exhibit intraspecific feeding diversity (Jangoux 1982), which has facilitated the success of these animals as keystone predators. Many prey species of *A. amurensis* are known from northern Pacific populations (Kim 1969a,b, Park & Kim 1985).

The work described here had two major objectives. It was designed firstly to investigate the diel feeding activity pattern of *A. amurensis* in the early winter, i.e. prior to spawning, and secondly, to determine whether *A. amurensis* in Tasmania exhibits prey selectivity or is a generalist on the most common species.

MATERIALS AND METHODS

Field Site and Collection

Field experiments were carried out at Nutgrove Beach, Sandy Bay, southeastern Tasmania (42°54'N, 147°20'E). Nutgrove Beach is considered to be typical of the Derwent River, where the Tasmanian population of *A. amurensis* is concentrated. The sediment is sandy-mud and the fauna is mainly infaunal. Very little zhard substratum exists, with the exception of rubbish which litters the riverbed. Macroalgae are also scarce at this site. Seastars were collected by hand and measured from the middle of the disc to the tip of the longest arm (Hancock, 1958); this is the radius (r).

Feeding Periodicity

To observe feeding activity in *A. amurensis*, SCUBA dives were conducted at Nutgrove Beach every two hours over a period of 24 h (from 1000 h, 31/5/95 to 0800 h, 1/6/95). Divers travelled parallel to the beach at a depth of 5 m. Seastars were overturned and recorded on underwater slates as digging, stomach extruded or neither, until approximately 100 seastars had been tallied. The presence of an extruded stomach is used in preference to the humped position, as *A. amurensis* remains flush with the substratum if the prey is very small. The seastars were further classified as juveniles (r < 55 mm) or adults (> 55 mm)(Byrne *et al.* 1997). Each successive dive was conducted up river from where the previous dive finished (approx. 50 m of beach per dive). This was done to prevent tallying seastars that had already been disturbed, which usually resulted in the expulsion of prey items. In addition, this procedure gave independence to each two-hourly sample.

The data (in percentage form) were transformed via angular transformation in order to comply with the assumptions of parametric statistics. Both single factor ANOVAs and two-factor ANOVAs without replication were carried out on the data.

Selectivity in the Field

Three SCUBA dives were conducted off Nutgrove Beach, southeastern Tasmania. Two were conducted at 5 m, approximately three months apart (on 22/6/95 and 30/9/95), and the third was conducted at 2 m (on 19/9/95) for a depth comparison. Each dive was carried out between 0900 and 1200 h. All seastars within 1 m either side of a 50-m transect were examined. Each seastar was recorded on an underwater slate as feeding or not feeding. Any debris attached to the arms was carefully brushed off and the seastars were then placed into numbered plastic zip-lock bags to prevent loss of stomach contents. Along the same transect line, ten circular PVC cores (100 mm deep, 98 mm diameter) were pushed into the sediment and dug out in order to determine the faunal composition of the substrata on each of the three dives. In the laboratory each seastar was measured (r) and its stomach folds examined for prey items. Pressure was applied to the aboral surface to expel engulfed food items. All prey items were measured and identified to the lowest possible taxon. Sediment from the core samplers was sieved (2 mm mesh) and any live animals were also measured and identified to the lowest possible taxon. Measurements taken were anterior-posterior length (bivalves), columella length (gastropods), basal diameter (cirripedes), carapace width (brachyurans), columella length (anomurans) and greatest test length (irregular echinoids).

Dietary composition was compared to the sites' faunal composition by calculating Vanderploeg & Scavia's (1979) relativised electivity index (E^*) as follows:

$$E^* = \frac{[W_i - (1/n)]}{[W_i + (1/n)]}$$

where W_i = selectivity coefficient calculated as

$$\frac{ri/pi}{\sum_i ri/pi}$$

r_i = relative utilisation of food types in the diet
p_i = relative availability of food types in the environment
n = number of available food types

The electivity index (E^*) given for each species has a range from –1 to 1. A value of 0 denotes that the species is taken in proportion to its abundance; 1 signifies that the species is preferred and selected at a greater proportion than is available; and –1 indicates that the species is avoided strongly.

A number of electivity indices exist. All are versions of Ivlev's (1961) original, differing only slightly from one another. In a review of the sampling characteristics of the variety of electivity indices, Lechowicz (1982) concluded that no one index ideally satisfies all criteria and that food types shown as preferred by one index will frequently appear as avoided by another. The review led to the recommendation of the use of Vanderploeg and Scavia's index. The range of values (–1 to +1) with a zero value for random feeding is a convenient property. However, the maximum preference value can only be attained under the unrealistic conditions that $r = 100$, $p = 0$ and the number of food types is infinite. For a more detailed discussion on the advantages and disadvantages of Vanderploeg and Scavia's and the other indices available the reader is referred to Lechowicz (1982).

RESULTS

Feeding Periodicity

The percentage of seastars feeding over the 24-h period is illustrated in figure 1. The data were grouped around the high and low tide times and analysed by a single factor ANOVA which revealed no significant correlation between the percentage feeding and the tidal variations ($F_{3,8} = 1.575$, $p = 0.270$). The first high tide and the first low tide for the 24-h period occurred within a short time frame and did not differ in magnitude; therefore, a single factor ANOVA was calculated with these two periods considered as one. However, there was still no significant difference in feeding activity between the tidal levels ($F_{2,9} = 1.928$, $p = 0.201$).

The data were then grouped according to periods of the day (i.e. noon, dusk, midnight and dawn). Again, there was no significant variation between these ($F_{3,8} = 0.340$, $p = 0.797$). In addition, the data were grouped according to daylight hours and nighttime hours. The single factor

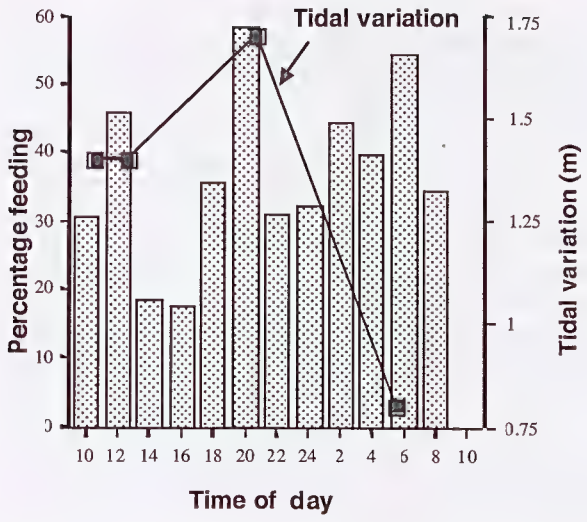

FIG. 1 — Percentage of Asterias amurensis *feeding over 24 h. Graph shows tidal height variation over the same period.*

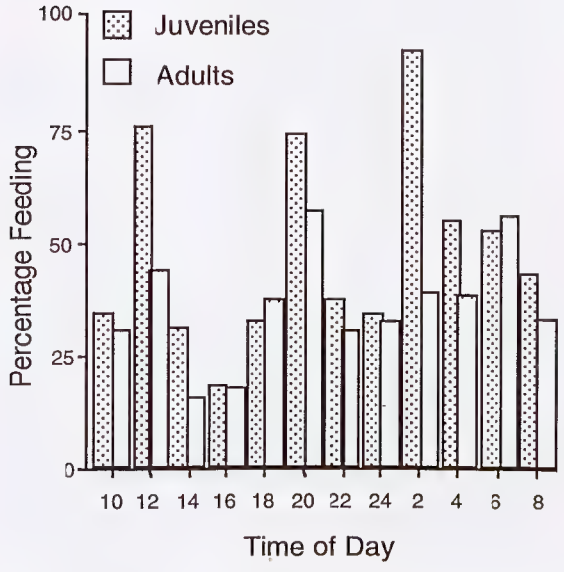

FIG. 2 — Percentage of juveniles and adults feeding over a 24 h period.

ANOVA again showed no significant difference between night and day ($F_{1,10}$= 0.960; p = 0.350).

A two factor ANOVA (without replication) revealed that the proportion of juveniles feeding was significantly higher ($F_{1,11}$ = 6.510; p = 0.027) than the proportion of adults feeding (fig. 2).

Selectivity in the Field

Combined June and Sept 1995 sample: 5 m

Dates of collections, seastar sizes and proportions feeding are given in table 1. Data from the two collections from 5 m were kept separate for a comparison of proportions of major prey types in stomachs but have been combined for the purpose of the electivity analysis. The percentage of seastars that were recorded as feeding was 44% (i.e. either had their

TABLE 1
A. amurensis field data on size and percentage feeding

Date	Depth (m)	Av. radius (mm±SE)	Range of r (mm)	% feeding	% with items in stomach
22/6/95	5	69 ± 11.8	30-113	50.0	76.5
30/9/95	5	72 ± 10.5	40-103	36.4	69.1
19/9/95	2	81 ± 13.8	46-134	30.0	76.0

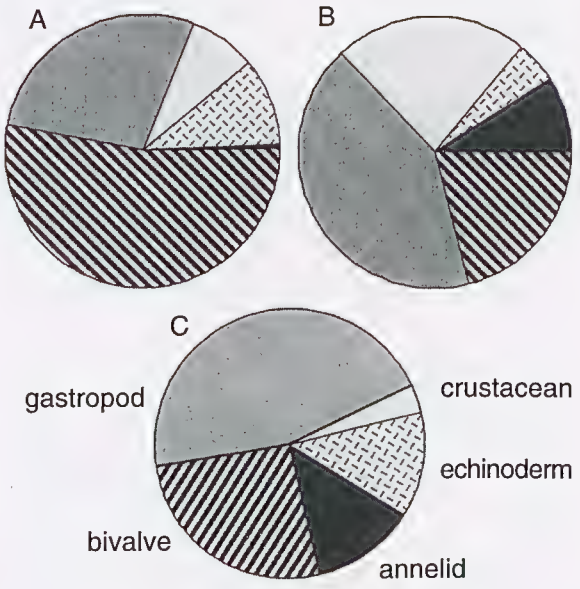

FIG. 3 — Proportions of prey types in the diet of Asterias amurensis. *(A) June samples at 5 m depth; (B) September samples at 5 m depth; (C) September samples at 2 m depth.*

stomach extruded or were in the process of digging). However, after examination of the stomach folds it was discovered that 73% contained at least one prey item. Hence both measures are included in the table for all occasions. The proportions of prey types in the diet are illustrated in figure 3. The results of the stomach content analysis, substrate faunal composition and the electivity indices are shown in table 2.

Bivalves were the most important prey type for this population of *A. amurensis* in June (fig. 3A), whereas gastropods were more important in the diet in September (fig. 3B). Non-molluscan prey types made up smaller proportions of the diet.

The most preferred prey was the bivalve *Notospisula trigonella* (E^* = 0.70) followed closely by *Chioneryx striatissima*, Veneridae sp. and *Placamen placida*. The crustacean *Phlyxia* sp. was also taken selectively. *Nassarius nigellus* was one of the most abundant macrobenthic species in the substrate and was consumed in the greatest numbers. A small hermit crab (*Pagurixus handrecki*), which is common at this site and depth, occupies the shells of *N. nigellus*. In earlier laboratory experiments it was not consumed by *A. amurensis* (Lockhart & Ritz 1998). Thus, it was assumed

TABLE 2
Numbers, proportions and size ranges of fauna found†

Species n = 20	Total number in 123 stars	Size range in 123 stars (mm)	Total number in 20 cores	Size range in 20 cores (mm)	*r*	*p*	E*‡
Mollusca: Bivalvia							
Mysella donaciformes	9	2.4–3.8	132	1.2–3.8	2.9	47.7	–0.92
Placamen placida	13	2.0–5.1	5	2.0–3.3	4.2	1.8	0.23
Tawera gallinula	5	2.1–5.9	5	1.4–2.6	1.6	1.8	–0.23
Chioneryx striatissima	94	1.2–5.0	11	2.0–5.6	30.6	4.0	0.68
Katelysia sp.	0		2	1.6–2.0	0	0.9	
Venerupis anomala	14	2.1–6.0	8	2.2–5.0	4.6	2.9	0.04
Hiatella australis	2	4.9–6.0	1	3.0	0.7	0.4	0.09
Cyamiomactra mactroides	0		1	2.0	0	0.4	
Notospisula trigonella	10	2.4–4.0	1	2.0	3.3	0.4	0.70
Veneridae sp.	3	2.5–3.5	1	1.6	1.0	0.4	0.27
Gastropoda							
Nassarius nigellus (gast.) §	98	1.8–10.0	62	1.8–10.2	31.9	22.4	–0.01
Nassarius nigellus (shell) §	10	2.2–7.4	0		3.3		
Odostomia deplexa	0		1	1.8	0	0.4	
Sinuginella pygmaeioides	0		1	5.1	0	0.4	
Fusinus novaehollandiae	0		6	6.6–110.0	0	2.2	
Conuber conicus	0		2	4.1–4.6	0	0.7	
Crustacea							
Phlyxia sp.	20	2.0–5.1	5	2.8–4.8	6.5	1.8	0.43
Halicarcinus sp.	5	3.2–5.2	3	6.0–10.0	1.6	1.1	0
Pagurixus handrecki	0		13	5.4–10.0	0	4.7	
Elminius modestus	18	1.0–5.4	0		5.9	0	
Echinodermata							
Echinocardium Cordatum	3	4.0–7.0#	7	9.0–38.0	1.0	2.5	–0.58
Annelida	3	#	10	#	1.0	3.6	–0.67
TOTAL	307		277		100	100	

† Found both in the stomach folds of *Asterias amurensis* (*r*) and in the substrate of Nutgrove Beach (*p*) at a depth of 5 m (combined June and September samples).

‡ Vanderploeg & Scavia's electivity index (*E**) shows those species which are preferred (positive *E**) and those which are avoided (negative *E**).

§ (gast.) & (shell) refer to those *N. nigellus* in the diet of *A. amurensis* in which remains of the gastropod were found or which were empty, respectively.

# denotes those prey items which were unmeasurable due to damage.

that the species consumed by *A. amurensis* was indeed the gastropod.

Species that were avoided (negative *E**) included (in decreasing order of avoidance) the bivalve *Mysella donaciformes,* the annelids, the echinoid *Echinocardium cordatum* and the bivalve *Tawera gallinula*. The annelids are most likely to have been underestimated in the diet as they are completely digested.

Some species were consumed but were not found in the core samples and, therefore, are considered to be taken selectively. These are *N. nigellus* empty shells and the barnacle *Elminius modestus*. The fact that no barnacles were found in the substrate is not surprising since, when they occur on soft substrates, they are usually associated with mussels (*Mytilus edulis*). The only mussels at the Nutgrove beach site were found attached to a chain that anchors a floating platform upstream of the immediate study area. A big storm had occurred just prior to the September dive, resulting in the detachment of the mussels (usually unattainable). The barnacles, therefore, were more readily available to the seastars but would most likely be found in the direct vicinity of the floating platform.

Species were found in the core samples which were not found to be consumed and, therefore, are considered to be avoided. These include the hermit crab *Pagurixus handrecki* and the gastropods *Conuber conicus* and *Fusinus novaehollandiae*. However, the latter is known to be consumed occasionally by *A. amurensis* (pers. obs.).

September 1995 Sample: 2 m

Dates of collections, seastar sizes and proportions feeding are given in table 1. The percentage of seastars that were recorded as feeding was 36.0% (26.0% with stomach extruded and 10.0% digging). After examination it was found that 76.0% of seastars contained at least one prey item in the stomach folds. The proportions of prey types in the diet of *A. amurensis* at 2 m are illustrated in figure 3C. The results of the stomach content analysis, substrate faunal composition and the electivity indices are shown in table 3.

Gastropods make up the largest proportion of the diet followed by the bivalves (fig. 3C). Non-molluscan prey again make up smaller proportions of the diet. Numerically the most commonly consumed prey was again the gastropod *N. nigellus*, which was found to be taken selectively ($E^* = 0.38$). Again no *P. handrecki* were taken and these, therefore, are considered to be avoided.

Species taken selectively included (in decreasing order of selectivity) the annelids, the echinoid *Echinocardium cordatum*, the gastropod *N. nigellus*, and the bivalves *Chioneryx striatissima* and *Placamen placida*. Species that were avoided are (in decreasing order of avoidance) the bivalves *Mysella donaciformes*, *V. anomala* and *T. gallinula*.

Other species considered to be preferred, as they were found in the stomach folds but not in the core samples, are the bivalve *Notocallista diemenensis*, the crab *Phlyxia* sp. and the barnacle *Elminius modestus*. Conversely, species considered to be avoided as they were found in the substrate but not in the diet are the bivalves *Katelysia* sp., *C. mactroides*, *H. australis*, *Tellina deltoidalis*, unknown *Mysella* sp., *Lasaea australis*, unknown *Veneridae* sp., the gastropods *Odostomia deplexa*, *Conuber conicus*, *F. novaehollandiae*, and the crustacean *Pagurixus handrecki* .

DISCUSSION

Feeding Periodicity

The average percentage of feeding *A. amurensis* was found to be 36.5 ± 9.7% with a range of between 17.2 and 58.2% of seastars feeding over all hours. This is surprising because asteroids are thought to remain inactive during most of the 24-h cycle (Valentincic 1983) and be relatively inactive in winter. The majority of non-feeding seastars were on the move with the tips of their arms curled in the characteristic

TABLE 3
Numbers, proportions and size ranges of fauna found†

Species n = 23	Total number in 50 stars	Size range in 50 stars (mm)	Total number in 10 cores	Size range in 10 cores (mm)	*r*	*p*	E*‡
Mollusca: Bivalvia							
Mysella donaciformes	1	2.2	69	1.0–4.0	1.4	46.1	–0.93
Mysella sp.	0		2	2	0	1.3	
Placamen placida	3	3.2–4.0	6	1.8–3.0	4.3	4	0.11
Tawera gallinula	5	1.6–2.4	13	1.2–3.8	7.1	8.7	–0.03
Chioneryx striatissima	5	2.6–3.8	8	2.0–3.0	7.1	5.4	0.2
Katelysia sp.	0		2	2	0	1.3	
Venerupis anomala	3	3.0–6.0	11	1.4–5.6	4.3	7.4	–0.19
Hiatella australis	0		1	3.2	0	0.7	
Cyamiomactra mactroides	0		1	1.4	0	0.7	
Tellina deltoidalis	0		1	11	0	0.7	
Lasaea australis	0		1	1.4	0	0.7	
Notocallista diemenensis	1	4.4	0		1.4	0	
Veneridae sp.	0		1	2	0	0.7	
Gastropoda							
Nassarius nigellus (gast.) §	20	2.2–10.0	22	1.6–4.4	28.6	14.8	0.38
N. nigellus (shell) §	10	1.4–9.4	0		14.3	0	
Odostomia deplexa	0		1	2.4	0	0.7	
Conuber conicus	0		1	4.4	0	0.7	
Fusinus novaehollandiae	0		1	61.9	0	0.7	
Crustacea							
Pagurixus handrecki	0		1	10	0	0.7	
Phlyxia sp.	2	–	0	2.9	0		
Elminius modestus	2	4.0–4.2	0	2.9	0		
Echinodermata							
Echinocardium cordatum	8	–	5	8.0–40.0	11.4	3.4	0.59
Annelida	10	#	2	#	14.3	1.3	0.85
TOTAL	70		149		100	100	

† Found both in the stomach folds of *A. amurensis* (*r*) and in the substrate of Nutgrove Beach (*p*) at a depth of 2 m (September).

‡ Vanderploeg & Scavia's electivity index (E^*) shows those species which are preferred (positive E^*) and those which are avoided (negative E^*).

§ (gast.) and (shell) refer to those *N. nigellus* in the diet of *A. amurensis* in which remains of the gastropod were found or which were empty, respectively.

# denotes those prey items which were unmeasurable due to damage.

foraging pose (Sloan 1980b). In comparison, many asteroid species feed at a much lower rate than this over winter, increasing their activities over summer (Paul & Feder 1975, Mauzey 1966, Paine 1969, Menge 1972, Keesing & Lucas 1992). Mauzey (1966) found that less than 5% *Pisaster ochraceus* were feeding over winter, which increased to 60% over summer. Paine (1969) found a similar seasonal difference in this species. This seasonal variation was thought to be because *P. ochraceus* is a temperate species, which is heat tolerant and, therefore, feeds more intensively over summer, because of an increase in metabolism. However, over 22 months the average percentage of feeding *P. ochraceus* was 35.4% (Mauzey 1966), which is very similar to the results from the present study over 24 h. *A. amurensis* is also a temperate species and, therefore, possibly will also increase its feeding activity as summer approaches.

It was not so surprising that the feeding activities of *A. amurensis* in the Derwent River at this depth did not correlate with the tidal variations. The high and low tides do not differ a great deal in magnitude at this time of year. In addition, a lull in feeding activity over the winter among temperate climate asteroids appears more strongly among intertidal individuals (Paul & Feder 1975, Sloan 1980a), being more affected by low temperatures and bad weather due to low-tide exposure (Menge 1971, Sloan & Robinson 1983). Natural diel feeding activity patterns for this reason are likely to be suppressed in inlets, bays, harbours and protected waterways (Feder 1970) such as the Derwent River.

During the present investigation, the first low tide occurred around noon and was followed by a lull in feeding activity, while the second low tide occurred just before darkness, during which time the percentage of feeding activity did not vary greatly. No significant difference was found when the data were grouped according to the tidal variations. However, the possibility of the tides and light interacting, as Menge (1972) suggests, cannot be ruled out. Further work should test the interaction of light and tides on the feeding activities of *A. amurensis*.

The non-significant differences revealed when the data were grouped according to different times of the day suggest that light does not play a primary role in controlling the feeding activities of *A. amurensis*. In contrast, the feeding activities of many asteroid species are strongly influenced by light. Most of these prefer to feed at night, such as *P. brevispinus* (Smith 1960), *Luidia sarsi* (Fenchel 1965), *Asterias rubens* (Thain 1971 in Sloan 1980a), *Acanthaster planci* (Ormond *et al.* 1973) and *Astropecten latespinosus* (Nojima 1981). Other species are known to feed at dawn and/or dusk (Mori & Matutani 1952, McClintock & Lawrence 1981, Beddingfield & McClintock 1993). *L. clathrata* exhibits one peak at dusk, although there is never 100% activity or inactivity at any one time (McClintock & Lawrence 1981). *A. bispinosus* is active at dawn and dusk over the summer months, having different activity peaks from coexisting predators (Ferlin-Lubini & Ribi 1978 in Sloan 1980a). Beddingfield & McClintock (1993) also related the foraging peak of *A. articulatus* to avoidance of predators, such as fish, which decrease feeding activity at dawn and dusk. If predator activity is a controlling factor of *Asterias amurensis* activities then this may explain the lack of foraging peaks in this species. Having no predators in Tasmania (Turner 1992), *A. amurensis* need not reduce its activities according to those of its predators. *Astropecten polyancanthus* also feeds at dawn and dusk (the intensity of activity being stronger at dawn), burying itself at noon and midnight (Mori & Matutani 1952). In this early study it was found that temperature played no role and that light and food were the controlling factors of this species' diel feeding pattern. Food was found to be a modifier of the intensity of activity, while light was shown to be the real controlling factor of the rhythm (Mori & Matutani 1952).

Prey availability cannot be ruled out as the factor controlling the feeding pattern of *Asterias amurensis* since prey appears to be scarce at this site. Thus, the level of hunger in these seastars may increase to the point where other controlling factors, such as tide levels and light, may be suppressed. Beddingfield & McClintock (1993) found that *Astropecten articulatus* spent significantly longer periods of time foraging when fed low quality food. A number of other researchers have reported similar findings e.g. Mori & Matutani (1952) studying the asteroid *A. polyancanthus*. Starved *L. sarsi* will consume a greater variety of prey species but at a reduced rate (Fenchel 1965). Such behaviour could explain the reason why species such as *F. novaehollandiae* are not preferred by *Asterias amurensis* but are consumed occasionally in the field (pers. obs.).

In the present investigation it was found that a significantly higher proportion of juveniles were feeding over 24 h than were adults. This could simply be an artefact of the very small number of juveniles found in the samples relative to the adults. Ferlin-Lubini & Ribi (1978 in Sloan 1980a), working on *Astropecten* spp., found that large individuals were active longer than smaller ones. Furthermore, the percentage of juvenile *Asterias vulgaris* found feeding was considerably less than that for the adults (Himmelman & Dutil 1991). Results from a laboratory experiment, comparing the feeding rates of a small size class and a large size class of *A. amurensis*, revealed that the former consumed a much greater percentage of its body weight than the latter, lending some support to the findings of the present diel investigation (Lockhart & Ritz 2001).

Selectivity in the Field

The most disturbing finding of the selectivity investigation is the physical size of the prey species inhabiting Nutgrove Beach. The majority of the bivalves, which make up the largest proportion of the infauna, were just a few millimetres in length. The gastropod *Fusinus novaehollandiae* was found in its full size range, but this abundant species was shown to be avoided by *A. amurensis*. Almost the entire size range of the gastropod *Nassarius nigellus* was also found, though large individuals of this species were rare. Empty adult shells of all the other mollusc species were found, some with obvious carnivorous mollusc drill holes, but most appeared undamaged, as would be the case if an asteroid had attacked. Many dives were conducted at this site during 1995 and no live adult bivalve specimens were ever observed, even when digging deep into the sediment. One species, *Paphies (Mesodesma) erycinaea,* was an exception. Since it occurs at water depths shallower than 2 m, this species is likely to be in a refuge where *A. amurensis* cannot feed at low tides or in rough weather (Robles *et al.* 1990). *N. nigellus* has been observed displaying a range of defence techniques (Lockhart & Ritz 1998) and this is likely to be the reason why adults of this gastropod can be found.

The layer of aerobic sediment suitable for burrowing bivalves is very thin at the site sampled and possibly most

of the Derwent River. This means that even adult prey might not be able to find a depth refuge by digging beyond the reach of the tube feet of *A. amurensis*, which is a very common avoidance technique of bivalves to asteroid predators (Kim 1969a, Allen 1983, Fukuyama & Oliver 1985). *A. amurensis* is known to be able to dig no deeper than 50 mm (Arima *et al.* 1972, Fukuyama & Oliver 1985). Increasing size of prey may increase the probability of location and capture when behavioural and depth refuges are not effective (Fukuyama & Oliver 1985). Furthermore, *A. amurensis* at this site probably prefers intermediate or larger sizes of a bivalve species whenever they can be captured, as has been shown to be the case for *A. rubens* (Allen 1983) and demonstrated experimentally for *A. amurensis* (Lockhart & Ritz 2001). Adults of these species are, therefore, extremely vulnerable to predation by *A. amurensis*. The aerobic layer thickens as the intertidal zone is approached and is likely to be another important factor allowing the survival of *P. (Mesodesma) erycinaea*, since this species is known to be a common prey item of *A. amurensis* (pers. obs.).

Field observations revealed that *A. amurensis* selected some prey types and avoided others. However, it must be kept in mind that observations of feeding in the field might provide a biased reflection of dietary choices if the times spent feeding on various prey differ (Day *et al.* 1995). Also, what has been interpreted as avoidance *of* prey might actually be avoidance *by* prey, since some are known to have active avoidance mechanisms.

With the exception of *N. nigellus*, the gastropods were shown to be avoided. Grannum *et al.* (1996) showed that *Sinuginella pygmaeioides* was also strongly avoided in their samples from Howrah Beach, southeastern Tasmania, in November. Feder (1959, 1963) described a range of defence techniques by gastropods which provide these species with a means of escape from *P. ochraceus*. The only two gastropods which are in a great enough abundance for inferences to be made in the present study are *N. nigellus* and *F. novaehollandiae*. However, the data for these two gastropods are not consistent with the hypothesis that gastropod escape behaviour can account for low selectivity by asteroids. As has already been mentioned, the gastropod *N. nigellus*, has been observed to display a full range of defence techniques. However, it is consumed by *A. amurensis* selectively. In contrast, *F. novaehollandiae* is strongly avoided, as would be expected from the findings of Feder (1959, 1963). Nevertheless, this species, which has been observed to be an occasional prey item of *A. amurensis*, was never observed to display defence techniques. It may have other forms of defence such as toxins. The abalone *Haliotis rubra*, for example, is known to possess a toxin in its epithelium which acts as a chemical deterrent to the asteroid *Coscinasterias muricata*, which only feeds on this species when preferred prey such as scallops are scarce (Day *et al.*, 1995). Bivalves were generally being consumed selectively or avoided by *A. amurensis*. *Mysella donaciformes* was strongly avoided, despite its great abundance. This result was also reported by Grannum *et al.* (1996), and Morrice (1995) did not record *Mysella* in stomach contents of *A. amurensis*.

Unfortunately, the E^* index is not amenable to parametric analyses (Lechowicz 1982). In addition, as the number of food types increases, E^* becomes vulnerable to sampling errors for those species which are rare in the diet and rare to moderately common in the environment (Lechowicz 1982), as would be the case in this investigation. Hence, making a depth comparison is difficult. Nevertheless, some differences in the diet spectrum of *A. amurensis* in 2 m compared to 5 m can be seen. Annelids were strongly selected at 2 m but apparently avoided at 5 m. Grannum *et al.* (1996) also showed that annelids were strongly avoided by *A. amurensis* throughout most of the year in their samples from Howrah and Richardsons Beaches. However, these differences could have been due to the nearly complete digestion of annelids recovered from stomachs and damage sometimes suffered by those from cores.

Diet and preferences for prey can vary with depth. Himmelman & Dutil (1991), in a study of the asteroids of the Gulf of St Lawrence, Canada, stated that changes in diet with depth strongly reflect changes in the prey available, as most prey species are highly localised in their distribution. However, in the present study, the relative proportions of *Chioneryx striatissima*, *Echinocardium cordatum* and the annelids did not appear to change with depth, probably due to the relative uniformity of the substrate. Thus, the reason for the changes in diet between *A. amurensis* at 5 m and at 2 m is probably due more to the fact that the majority of prey at Nutgrove Beach were relatively rare. *A. amurensis* is a highly mobile asteroid (Grannum, pers. comm.) which often continues to forage while still digesting a formerly engulfed prey item and then expels a number of prey items at once (Lockhart & Ritz 1998). Also, *A. amurensis* was observed on a number of occasions to move around and up the walls of aquaria while clutching a prey item at the oral region or with just one or two distal tube feet, even after it had already been feeding on the prey item for a number of hours (Lockhart & Ritz 2001.). Thus, *A. amurensis* at one of the depths investigated in the present study may actually have travelled quite a distance before either settling down to feed, or whilst continuing to digest, when it was examined. This habit could, therefore, explain why little difference in the diets of *A. amurensis* at the two depths was seen, especially since the horizontal distance from 2 m to 5 m is only approximately 5 m as the riverbed slopes steeply between these depths.

Two major threats have become apparent from the findings of the present diel study. Firstly, native predators may be outcompeted if they feed according to some diel pattern other than over the entire 24 h, e.g. if the diel feeding activity pattern of native predators includes periods of 100% inactivity. For example, *Coscinasterias muricata*, a native of Tasmania, forages only during daylight hours, while the nocturnal hours are spent either near the shelter of rocks or continuing to digest prey items captured during the day (Day *et al.* 1995); it is, therefore, likely to be outcompeted by this most adaptable introduced pest. Secondly, predator behaviours are thought to assume greater importance if refugia do not exist (Robles *et al.* 1990). Therefore, due to the high proportions of the population feeding throughout a 24-h period, its locally high densities, and the apparent lack of prey refuges, including temporal, depth and size, as an introduced predator, *A. amurensis* is predicted to have major detrimental effects on the native marine fauna of Tasmania.

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SIZE SELECTIVITY AND ENERGY MAXIMISATION OF THE INTRODUCED SEASTAR, *ASTERIAS AMURENSIS* (LÜTKEN), IN TASMANIA, AUSTRALIA

by S.J. Lockhart and D.A. Ritz

(with two tables and five text-figures)

LOCKHART, S.J. & RITZ, D.A., 2001 (31:xii): Size selectivity and energy maximisation of the introduced seastar, *Asterias amurensis* (Lütken), in Tasmania, Australia. *Pap. Proc. R. Soc. Tasm.* 135: 35–40. ISSN 0080–4703. Department of Ocean Sciences, University of California, Santa Cruz, USA (SJL); School of Zoology, University of Tasmania, GPO Box 252-5, Hobart, Tasmania, Australia 7001 (DAR).

The selectivity of the introduced north Pacific seastar, *Asterias amurensis*, for different sizes of prey was investigated with the aim of predicting the impact this species will have on the age structure of native prey species and, thus, on their survival. The energy maximisation capabilities of *A. amurensis* were assessed. The time small *A. amurensis* (r= 56–77 mm) spent handling the mussel *Mytilus edulis* increased exponentially with increases in mussel size; handling time by large seastars (r= 78–86 mm) only increased when eating the largest mussels offered. Mussels of the size class 20–29 mm were preferred. The energy content of six mussel size classes was divided by the handling time of each to give a prey value. The optimal mussel size class was calculated to be 30–39 mm. Thus, *A. amurensis* was not shown to maximise its energy by consuming mussels of a size that would give the greatest energy return for the energy expended. Smaller seastars consumed a greater percentage of their body weights per day (4.97%) than did larger seastars (2.57%).

Key Words: ***Asterias amurensis*, energy maximisation, introduced species, optimal foraging, seastar, size selectivity, Tasmania.**

INTRODUCTION

The northern Pacific seastar, *Asterias amurensis*, has established itself in southeastern Tasmanian waters after being introduced, probably as larvae transported in the ballast waters of ships, sometime in the 1980s (Turner 1992, Buttermore *et al.* 1994, Morrice 1995, Byrne *et al.* 1997). It was first collected in 1986 but not correctly identified until 1991 (Turner 1992, Buttermore *et al.* 1994, Byrne *et al.* 1997). *A. amurensis*, is considered a major pest within its native range, preying on commercial scallops and a great variety of other benthic invertebrates (Hatanaka & Kosaka 1959).

Predators often select the size of prey they eat. This behaviour can have important effects on the age structure and spatial distribution of a prey population (Landenberger 1968). There are a number of factors that affect the selection of various sized prey: ease of manipulation, available stomach area and maximal energy intake per unit time (McClintock & Lawrence 1981, Beddingfield & McClintock 1993). Seastars often show a preference for bivalves and gastropods which are significantly smaller than the mean size of those available (Christensen 1970, Doering 1981, McClintock & Lawrence 1981, 1985, Beddingfield & McClintock 1993). The maximum size in shell length eaten by the seastar *A. amurensis*, differs slightly according to the amount of food already in the predator's stomach and the quantity of suitably sized food found in the environment (Kim 1969). Even the largest seastar, *Pycnopodia helianthoides*, can maintain itself on small prey items (Paul & Feder 1975). However, this is in contrast to the habits of the seastars *Asterias rubens*, *Pisaster* spp. and *Leptasterias hexactis*, where large size is dependent on a plentiful supply of large prey items (Larsson 1968 in Paul & Feder 1975, Feder 1970, Menge 1972).

Size selectivity can be considered a process of optimal foraging, whereby different sizes of prey represent different prey values (energy content/handling time) to a predator. The consumption of an optimal size (i.e. of greatest prey value) maximises the net energy gain for a predator. Hughes (1980) stated five rules involving the selection of prey of differing values by which, according to optimal foraging theory, a predator should forage. These are:

(1) a predator should consume the highest ranking prey;
(2) a predator should consume suboptimal prey when optimal prey are scarce;
(3) the highest ranking prey should always be consumed no matter how infrequently encountered;
(4) when recognition time is significant, lower ranking prey may be consumed if they are frequently encountered, even when optimal prey are plentiful;
(5) when recognition time is zero, lower ranking prey should never be consumed if optimal prey are plentiful.

The direct comparison of prey value curves with size frequency of prey in the diet has only been attempted in a few studies (Hughes 1980). To the authors' knowledge, no studies of this kind, focusing on asteroids, have previously been conducted.

This experiment is designed to investigate the selectivity of *A. amurensis* for different sizes of the mussel, *Mytilus edulis*, with the aim of predicting the impact this species will have on the age structure of native prey species. Also, in selecting particular prey sizes, the energy maximisation capabilities of *A. amurensis* can be assessed and thus, these results will help predict its success and impact in Tasmania.

MATERIALS AND METHODS

Experimental Animals

Seastars in each of two size classes were collected from both Nutgrove Beach and off the wharfs of the Derwent Sailing Squadron, Hobart (147°20'E, 42°56'N). The small size class ranged from 56–77 mm (radius)(av. 63.4 mm ± 6.5 SD) and the large size class ranged from 78–86 mm (av. 81.2 mm ± 1.9 SD). Because of small sample sizes, both

classes were combined in experiments to determine prey size selection and handling time. All mussels (*Mytilus edulis*) were collected from off the Derwent Sailing Squadron wharfs and were cleaned of barnacles. Each seastar was held in a separate aquarium, filled to a depth of 150 mm with fresh seawater, of salinity 33 % ± 2 SD, filtered through activated charcoal (EHEIM, 2213). Seastars were acclimatised at 12°C without food for 24 h before experiments began to standardise hunger levels.

Handling Time

Handling time was investigated using time lapse video (Panasonic, FS 90) to accommodate 24 h of filming onto a 4 h tape. The camera (Panasonic, WV BL 600) was directed at an aquarium separated into four compartments, each of which held a single seastar, two of each size class. Mussels of six size classes (i.e. <10 mm; 10–19 mm; 20–29 mm; 30–39 mm; 40–49 mm; 50–59 mm; 60–69 mm) were presented to each of the four seastars in random order to reduce any bias due to the effect of accumulating satiation, and the following events were timed:

(1) *Orientation Time (To). To* was defined as the time from the seastar's first physical contact with the mussel, through the period of orientating the mussel into position for feeding, until the seastar ceased movement.
(2) *Feeding Time (Tf). Tf* was defined as the period from the end of *To* to the abandonment of the empty shell.
(3) *Handling Time (Th). Th* was defined as the sum of *To* and *Tf.*

Mussel Energy Content and Prey Value

The energy of mussel flesh (*E*) was measured in a micro-bomb calorimeter after the flesh from mussels of known shell length was dried for 24 h at 70°C. The energy contents of five mussels in each size class were measured. With the exception of the two smallest mussel classes (for which the entire volume of flesh could be used), two subsamples were taken and averaged for each of these five mussels in each of the six size classes. To test for a variation in energy content between the different mussel size classes the results were subjected to a one-way ANOVA. The smallest mussel size class (i.e. <10 mm) was not included in this analysis.

Prey value was defined as *E/Th.* These definitions ignore any differences in the metabolic costs of the various handling activities.

Size Selectivity

Due to a lack of aquaria and space, all seastar sizes could not be tested at the same time. However, every effort was made to reproduce all experimental conditions. Each experiment ran for two weeks. Five aquaria (45 × 40 cm) were set up, each held five mussels (of known weight) of each of the six mussel size classes scattered over the bottom. Five seastars of a size class (i.e. 56–75 mm or 76–95 mm) were placed individually in each. An automated lighting system illuminated the aquaria for 12 h each day. At least once every 24 h each aquarium was examined and any empty shells were weighed and replaced by a mussel of the same size class to maintain prey availability. At the end of each week all mussels were replaced with freshly collected ones.

RESULTS

Handling Time

A significant difference between the handling times of the various mussel size classes was obtained when all seastar sizes were combined ($F = 15.594$; $df = 4/15$; $p < 0.001$) (fig. 1). The resultant variance was shown to increase exponentially with an increase in mussel size. Thus, the natural log (ln) of *Th* was calculated and plotted against mussel size, giving a linear relationship ($r^2 = 0.732$, $F = 54.613$, $df = 1/20$, $p = 0.0001$; fig. 2). Predictions of prey value were calculated from this relationship.

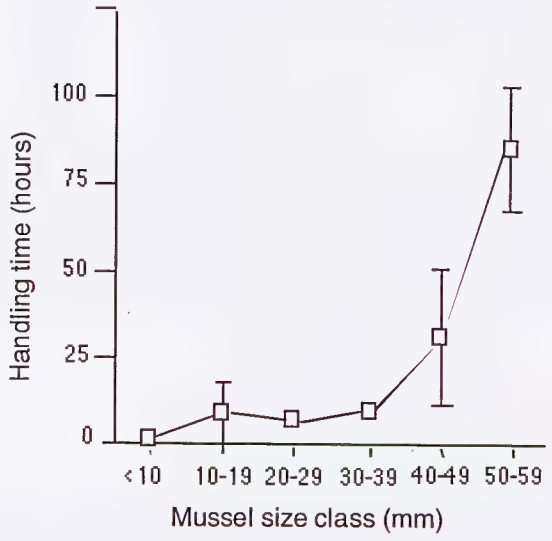

FIG. 1 — Handling times for the seastar Asterias amurensis feeding on a range of mussel size classes.

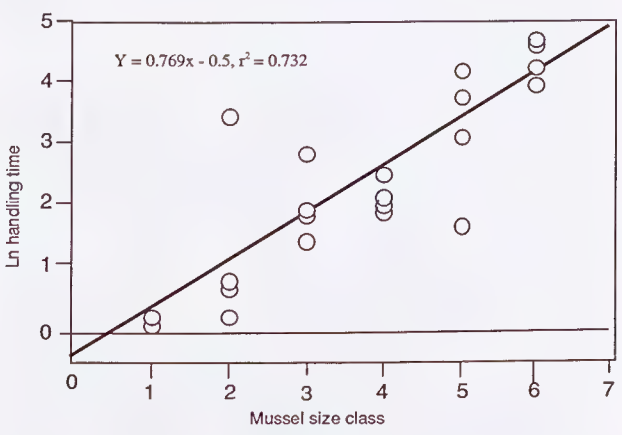

FIG. 2 — Relationship between the natural log (ln) of Th *for* Asterias amurensis *feeding on six mussel size classes (where 1 = <10 mm; 2 = 10–19 mm; 3 = 20–29 mm; 4 = 30–39 mm; 5 = 40–49 mm; 6 = 50–59 mm).*

Mussel Energy Content and Prey Value

The energy contents of the six mussel size classes (table 1) were not shown to be significantly different (single factor ANOVA; F = 2.55; df = 5/24; p = 0.055). Therefore, the energy content (kilojoules per gram of ash-free dry weight) of all the mussel size classes were averaged before prey value was calculated.

The average mussel energy content (19.09 KJg^{-1}) was multiplied by the average dry weight of each mussel size class, then divided by each respective handling time (calculated from the natural log regression) to give a prey value of seven mussel size classes (fig. 3). The optimal mussel size class (i.e. mussel size class of greatest prey value) was found to be 30–39 mm.

Size Selectivity

The size range and number of mussels consumed by the seastars (n = 10) is shown in figure 4. ANOVA revealed that the preference for different mussel size classes was significantly different (F = 4.080; df = 6/63; p = 0.002). t-tests revealed that mussels of 20–29 mm were shown to be significantly preferred to those of the size classes <10 mm (p = 0.028), 40–49 mm (p = 0.004), 50–59 mm (p = 0.003) and 60–69 mm (p = 0.001) but not significantly preferred over the size classes 10–19 mm (p = 0.914) or 30–39 mm (p = 0.055).

Preferred vs Optimal Mussel Size Class

The combined data of mussels consumed by the two seastar size classes were compared to the calculated prey value for each mussel size class (fig. 5). *A. amurensis* was found to prefer the mussel of a size 20–29 mm; a size class smaller than the calculated optimal mussel size class, 30–39 mm. Thus, these results suggest that *A. amurensis* did not feed optimally.

Feeding Rates

The data collected allowed calculations of feeding rates of the two original seastar size classes to be made. These results are listed in table 2.

Both size classes consumed on average approximately one mussel per day. The larger seastars consumed marginally more mussel flesh per day than did the smaller ones. However, the smaller seastars consumed closer to double the percentage of their body weights per day (4.97% vs 2.57%) than did the larger seastars.

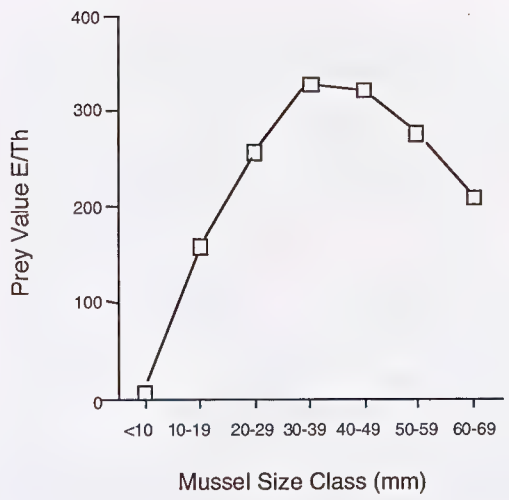

FIG. 3 — Calculated prey value (E/Th) of seven mussel size classes for Asterias amurensis. *(N.B. prey value was estimated for an extra mussel size class from the linear regression of ln handling time and mussel size).*

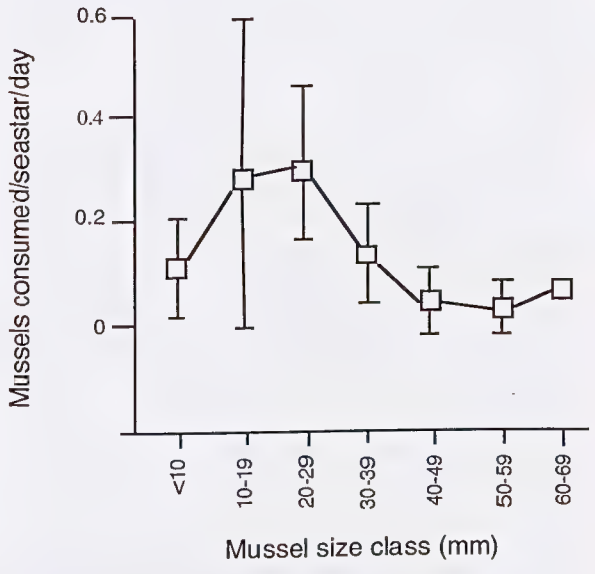

FIG. 4 — Number of mussels consumed per seastar per day.

TABLE 1
Energy content* of seven *Mytilus edulis* size classes

Mussel size class (mm)	<10	10-19	20-29	30-39	40-49	50-59	60-69
Energy content (KJg^{-1})	12.61 ± 2.65	21.96 ± 2.19	19.72 ± 2.35	14.98 ± 5.21	17.35 ± 2.09	21.17 ± 1.94	19.39 ± 1.78

* KJg^{-1} of dry weight.

TABLE 2
Feeding rates of two size classes of
Asterias amurensis on *Mytilus edulis*

Seastar size class	Average consumed/ star/day (g)	Average number consumed/ star/day	Average body weight consumed/ star/day
Small	1.39 ± 0.49	0.80	4.97 ± 2.37
Large	1.48 ± 0.62	0.87	2.57 ± 1.44

DISCUSSION

Despite efforts to standardise hunger levels, the time taken by *A. amurensis* to handle and consume *Mytilus edulis* varied considerably amongst seastars of the same size, which has also been observed for *A. rubens* by Allen (1983). The mussel size classes, as explained, were presented to each of the four seastars in random order, but unfortunately temporal constraints prevented standardisation of digestive pauses (Galtsoff & Loosanoff 1939) between each mussel consumed. The long periods of time needed to consume one prey item also make larger numbers of replicates desirable than were possible in the present study. Furthermore, the possibility that some of the seastars may have benefited from previous experience with mussels prior to capture cannot be ruled out.

Asteroids feed on mussels by using a combination of a pulling force exerted by the tube feet and inserting the very thin stomach folds into gaps as small as 0.1 mm wide (Binyon 1972, Jangoux 1982). Gaps exist naturally in most bivalves even when closed, usually where the byssus threads emerge (Feder 1955). *Th* was found to increase exponentially with increase in mussel size. Shaw (1988) found that the handling time of *Coscinasterias calamaria* also increased exponentially with increase in mussel size. The long *Th* and the variation of *Th* between seastars in the present study could have been due to their reproductive status, since the present experiments were conducted within the spawning period of *A. amurensis* in Tasmania (Morrice 1995).

The many video-taped hours in the current investigation allowed for some interesting observations on the handling of mussels by *A. amurensis*. The seastars generally sensed the mussels immediately after they had been placed in the aquaria; evidenced by the curling of the arm tip closest to the mussel and the extension and waving of the terminal or sensory tube feet of the same arm tip (Sloan 1980). The seastars immediately proceeded to crawl on top of the mussel and spent anywhere from 1.5 min to 2.5 h (with an average of 14 min) in orientating the mussel (*To*). During this time the seastar rotated, presumably exploring the mussel for weaknesses or gaps and the best position to begin opening it. After this time, the seastars remained still, attempting to open the mussel, for long periods. However, the feeding time (*Tf*) was interspersed with periods during which the seastar would move position, sometimes attacking the mussel from the side instead of from above in the characteristic humped posture. In addition, the seastars occasionally abandoned the mussel for periods, or moved up and around the walls of the

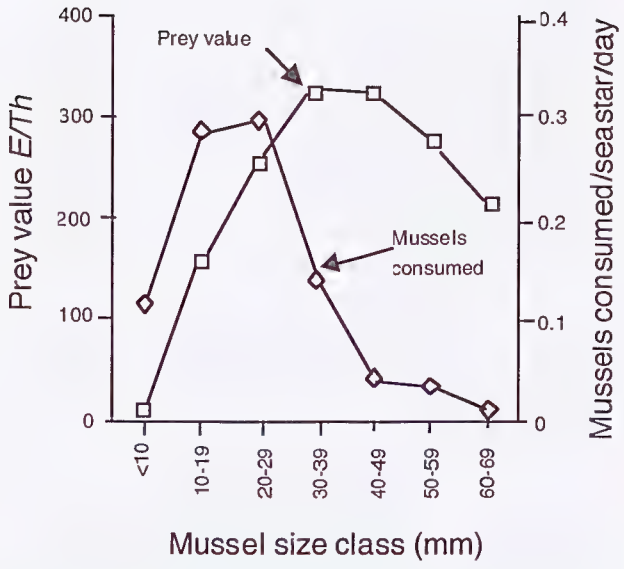

*FIG. 5 — Prey value (*E/Th*) of seven mussel size classes compared to those mussels consumed per seastar per day.*

aquaria with the mussel held at the oral region by the buccal tube feet or dragged behind, attached by only a few tube feet. Even though some seastars remained on a mussel until digestion of the flesh and adductor muscle was complete, it does not necessarily mean they fed continuously. The original time spent in orientating the mussel, the frequency and duration of further orientating periods or the frequency and duration of time spent moving around the aquarium, with or without the mussel, did not seem at all related to the size of the mussel or to the size of the seastar. These periods are probably more closely related to the satiation level or the nutritional requirements of individual seastars and may be an interesting topic for research. The ability of the seastars to travel with prey items may be adaptive in several ways: it may enable *A. amurensis* to move a prey item away from the intertidal zone, to prevent exposure, or from other areas with unfavourable conditions, while feeding; it may serve to avoid conspecifics "stealing" prey items; and/or it may provide a means for temporarily "storing" prey items until hunger reaches a level when the seastar needs to feed again, due to the need for a digestive pause (Galtsoff & Loosanoff 1939, Holling 1965 in Norberg 1977, pers. obs.).

A. amurensis was shown to prefer mussels of a size between 20 and 29 mm in length; a much smaller size class than the mean size available. A number of asteroids (Christensen 1970, Penney & Griffiths 1984, Fukuyama & Oliver 1985, Beddingfield & McClintock 1993) and indeed crustaceans such as crabs (Elner & Hughes 1978) and lobsters (Robles *et al.* 1990) are known to select prey of smaller sizes than the mean size available. For example, *Astropecten spp.* select small and juvenile bivalves although, unlike *Asterias amurensis*, they feed intraorally and kill their prey by anoxia (Christensen 1970, Beddingfield & McClintock 1993).

The fitness of a foraging animal is a function of the efficiency of foraging measured in terms of some "currency", usually energy (Pyke *et al.* 1977). Many studies have shown that animals select prey of high profitability, which includes optimal prey sizes. Feder & Christensen (1967 in O'Neill *et al.* 1983) explained that, as bivalve size relative to the

seastar size increases, the efficiency of the force exerted to open the prey becomes limiting. Also, large seastars feeding on very small prey will not be effectively utilising the full digestive capabilities of the stomach. *A. amurensis* did not prefer the size class of *M. edulis* that was calculated as being the greatest value as prey: 30–39 mm. Selecting smaller mussels may be a way of avoiding direct competition from conspecifics since they can be consumed in a shorter period of time. However, the size class 20–29 mm was not significantly preferred over "suboptimal" mussel size classes. *A. amurensis* was also expected to be capable of assessing the value of a prey item and to consume those items which would give the greatest energy return for the energy expended in handling the prey, thus maximising its energy intake. Elner & Hughes (1978) observed that the crabs manipulated prey in their chelae before accepting or rejecting, thereby making an active choice. *A. amurensis* also appeared to make an active choice. Each seastar often travelled around the tank and over the mussels, occasionally stopping to adopt a humped posture before moving on and finally consuming a mussel. However, the 20–29 mm mussel size class was not significantly preferred over the optimal size class (i.e. 30–39 mm).

An alternative hypothesis could be that there was a variation in the nutritional status of the mussels; both those used to measure *Th* and those used to establish size selectivity. The sex, reproductive status and the presence of pea crabs, *Pinnotheres hickmani*, could all vary the nutritional value of the mussels. Also, ingestive conditioning may be involved, whereby handling of specific prey types and sizes are improved with experience. This leads to an increase in the prey value (Hughes 1980).

Size selectivity is dependent on the prey to predator ratio and, thus, optimal prey sizes are expected to increase with an increase in predator size. The long handling times, resulting in few replicates, meant that this could not be fully examined in the present study. However, an increase in the size of prey selected with an increase in the size of the predator has been shown in a number of other studies, such as for the asteroid *A. vulgaris* (O'Neill *et al.* 1983) and the lobster *Panulirus interruptus* (Robles *et al.* 1990). Kim (1969) found that *A. amurensis* in Japan, of similar sizes to those used in the present study, preferred *M. edulis* of 20–40 mm in length, and the largest mussels consumed were, on average, 0.7 times the seastars' radius. However, these seastars were capable of consuming *M. edulis* that were equal in length to the radius of the seastars. These results are virtually the same as those found for the Tasmanian population of *A. amurensis* in the present study.

The significance of size selective feeding is thought to be that predator and prey can coexist because the surviving large prey may make a reproductive contribution that is disproportionately greater than their abundance (Paine 1976). However, aggregations of *A. amurensis* can lead to sharing of prey items so that large prey sizes, which could not normally be consumed by individuals, can be consumed by cooperation with conspecifics (Lockhart & Ritz, pers. obs.). Regardless, few mussels larger than the largest consumed by the seastars in the present study (60–69 mm) could be found on the Derwent Sailing Squadron wharfs. Thus, coexistence of *A. amurensis* and this native prey species by reaching a size refuge is, although possible, not as likely as that found by Paine (1976) with *Pisaster ochraceus* and its prey, *M. californianus*. Nevertheless, spatial refuges for prey are possible in the high intertidal zone, on moorings and other areas which are not easily accessible to *A. amurensis*. Through size selective feeding by *A. amurensis*, shown in the present investigation, this predator may affect the age structure of prey populations by foraging intensively on intermediate sizes. This could result in maintenance of a bimodal distribution in some prey populations as this species is believed to do in Norton Sound, Alaska (Fukuyama & Oliver 1985).

In the present study, *A. amurensis* of the smaller size class was shown to consume *M. edulis* at the daily rate of 4.97% of wet body weight and the larger seastars consumed 2.57%. A number of studies on asteroids have included feeding rates on mussels. Feder (1970) found that *P. ochraceus*, a well-known voracious predator, consumed mussels at a daily rate of 1.1% of their wet body weight in the late winter to early spring. As in the present investigation, smaller *P. ochraceus* were shown to consume much more than their larger conspecifics, at 6–11% (Feder 1970). O'Neill *et al.* (1983) also found that smaller *A. vulgaris* consumed a greater percentage of their body weights than did larger conspecifics. On average, Feder (1970) and Hancock (pers. comm. in Feder 1970) found that *P. ochraceus* and *A. rubens* respectively consumed no more than 3% of their wet weight per day, which approximates the results found here for *A. amurensis*. Feeding rates of *C. muricata* are of particular interest, as this species is likely to be a competitor of *A. amurensis* in Tasmania as it preys on many of the same species. Bell (1977) found that *C. muricata* consumed 0.25 mussels per seastar per day, which is much less than that found for *A. amurensis*. However, it was calculated that *C. muricata* consumed from 3.9 to 5.1 % of their wet weight per day, which is similar to the results of the present study. Hatanaka & Kosaka (1959) calculated that *A. amurensis* in Japan could consume 193 g of soft bivalve parts per seastar per year. On the basis of the results presented here it is estimated that *A. amurensis* in Tasmania could potentially consume on average 515 g per seastar per year.

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IMPACTS OF DIEBACK AT PINE LAKE, TASMANIA

by Jennie Whinam, Nicki Chilcott and Tim Rudman

(with six tables, five text-figures and one appendix)

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The possibility of a new plant disease in alpine plant communities was identified in 1994, following an investigation of dead and dying plants in the Central Plateau Conservation Area. Seven areas of dieback were identified within the affected catchment and monitored. Symptoms included leaf discolouration, loss of foliage and plant death. No disease of this type has previously been recorded in the Australian alpine environment. Temporal and spatial patterns in disease development along with evidence of lesions on plant roots suggested a soil and water-borne pathogen could be contributing to the dieback. A species of *Phytophthora* was isolated from plant material collected at the site.

Investigations have focussed on whether plants at the limits of their range have been more susceptible to a combination of below-average rainfall, above-average temperatures and the presence of pathogens. Initial rapid development of disease symptoms suggested the potential for local extinction of species, including Tasmanian endemics such as *Athrotaxis cupressoides,* and significant alteration to community structure through a loss or substantial reduction in the tree and shrub layers. However, longer term monitoring suggests short-term disease events followed by recovery of surviving plants with only localised impacts. Management actions have been concentrated on containment, monitoring impacts and investigation of the cause of the dieback.

Key Words: Pine Lake dieback, Tasmania, ecology, alpine, disease monitoring, *Phytophthora*.

BACKGROUND

Symptoms of recent dieback were observed at a number of sites in the vicinity of Pine Lake and Mickeys Creek in the Tasmanian Central Highlands (fig. 1). The dieback appears to have first occurred in the vicinity of the Pine Lake Boardwalk, below the outfall of a road culvert. In November 1990, two recently dead pencil pines, *Athrotaxus cupressoides,* were observed at Pine Lake. Other pines at the site appeared healthy with new seasonal growth. Soil samples were taken for pathogen screening; however, no indication of the cause of death was forthcoming. In May 1994, it was observed that there had been an increase both in the area affected by dieback and the number of dead plants at Pine Lake below an area of roadworks (Whinam 1994). A range of plant species was affected in a small area, and a temporal sequence of disease development spreading from the centre of the patch outwards was evident. This suggested the possibility of a new and potentially serious disease in subalpine conifer and heath communities. A second patch of dead pines was also observed on the northern shore of Pine Lake, in an area undisturbed by roadworks. A list of dead and dying plants was compiled, and soil and plant samples were collected for analysis. Parks and Wildlife Service staff and recreational users were requested to report any areas of dieback observed for follow-up investigation.

In 1994, a microscopic root rot fungus was found in association with dieback from a diseased *Richea scoparia* at Pine Lake (Wardlaw 1995). This fungus was thought to be an undescribed species of *Phytophthora* known from North America, which had been associated with plant disease in fir and some fruit and berry crops. Another fungus, identified as *Pythium* sp., was also isolated from the site. In response to a potentially new disease incursion to Tasmania, with possible effects on the subalpine plants at Pine Lake and the fruit and berry industries in Tasmania, a quarantine area at Pine Lake and a research program to investigate the *Phytophthora* were initiated.

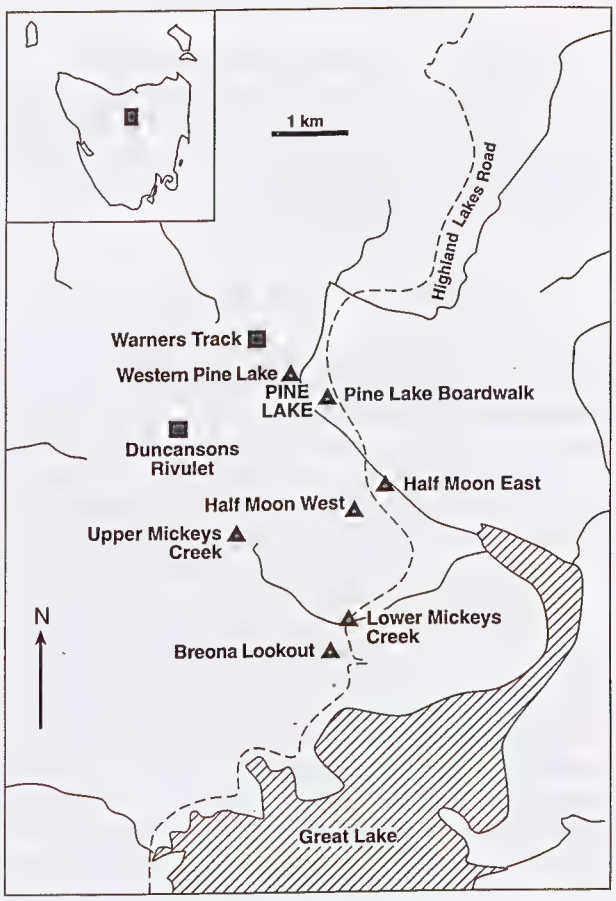

FIG. 1 — Dieback monitoring sites (triangles) near Pine Lake, Central Plateau, Tasmania and the two control sites (squares).

The identification of a potential pathogen not previously recorded in Tasmania indicated a potential incursion which required a quarantine response. As this was a new record for Australia and the first record of *Phytophthora* at high altitude, a response plan was implemented by the Parks and Wildlife Service to ascertain the significance of the find (Rudman & Whinam 1995). The plan consisted of three components: interim quarantine, monitoring disease impacts, diagnosis of cause.

The identification of potential pathogens and determination of cause were undertaken in partnership with the University of Tasmania (Chilvers 1998, Mohammed & Shanahan 2000). This paper addresses the monitoring conducted at Pine Lake and describes the process of containment. The role of local climate on change in plant health is investigated.

SITE DESCRIPTIONS

Pine Lake and the surrounding study areas are located at the northeastern edge of the Central Plateau at an altitude of about 1200 m (fig. 1). The Central Plateau is a broad, undulating highland area in central Tasmania (Pemberton 1986).

Public Use of the Area

The observed impacts of Pine Lake dieback indicate that the values for which the World Heritage Area (WHA) was declared are being adversely affected. There is a long history of public use of the Central Plateau for hunting, fishing, walking, skiing and sightseeing activities, which are provided for in the WHA Management Plan.

Geology and Vegetation

The Pine Lake region covers the area immediately south of the Central Plateau rim and consists of undulating terrain containing large numbers of lakes, as a result of recent glaciations. The area consists of rocky ridges, hills and swamps, and is underlain throughout by Jurassic dolerite with relatively simple yellowish-brown gradational soils. Exposed peats around Pine Lake are subject to serious frost heave problems, having lost the protective insulation of vegetation (Pemberton 1986).

Vegetation communities in the Pine Lake region form a mosaic which appears to vary in response to changes in altitude, climate, topography and soil drainage. Areas covered by peat usually have a dense cover of vegetation dominated by *Richea* spp. and bolster plants, with dense *Astelia alpina* beds around creeks. Interspersed with this vegetation are *Empodisma minus*, *Baloskion australe* and *Lepidosperma filiforme*. *Sphagnum cristatum* beds are often found in poorly drained hollows and sometimes form raised bogs, while scattered stands of the endemic pine *Athrotaxis cupressoides* inhabit fire-protected sites. The study area contains significant numbers of mature (up to 800 years) and young *A. cupressoides* (Whinam 1994). Heathland is dominated by *Orites* spp. (Pemberton 1986). This area has a high number of rare and threatened species and communities, many of which provide important evidence of major evolutionary processes (Kirkpatrick *et al.* 1993). Many of these species are local endemics, which are centred on the Central Plateau (Whinam 1994).

Climate

The climate of the Central Plateau area, including Pine Lake is cool to cold maritime, strongly influenced by prevailing northwest and southwest winds, which are ice-bearing throughout much of the long winter. Cloud frequently descends below 1100 m and minimum temperatures often fall below 0°C in winter. At Liawenee (the closest weather station to the Pine Lake area), the maximum monthly temperatures in summer are below 18°C (Corbett 1996). The annual average temperature on the Central Plateau varies between 4° and 7°C. Frosts can occur during any month, with July having the highest frequency. Annual rainfall at Liawenee, where it falls on about 200 days of the year, is about 1000 mm per year (Marsden-Smedley 1994). Annual average rainfall at Pine Lake is 1800 mm (Whinam 1994). Rain, snow, hail, fog, mist and rime contribute to precipitation in the study area (Whinam 1994).

METHODS

Climate Analysis — Warm-and-Dry Index

The index, developed by the Bureau of Meteorology (Barnes-Keoghan, unpubl. data), is meant as a simple method of detecting months that were particularly warm and especially dry. It is a number, from –100 (representing cool and wet) to +100 (warm and dry). Available data were obtained from weather stations at opposite ends of the Plateau: Liawenee (monthly means of daily maximum temperature and total monthly precipitation) and Meander (total monthly precipitation) for the period 1984 to 1999. Each monthly rainfall total was then ranked against the same month in other years, producing a number from 0 (the driest year) to 100 (the wettest). This is transformed into a Dryness Index which runs from –100 (in the wettest year) to +100 (in the driest). The temperatures were treated in the same way to yield a Warmness Index between –100 (in the coolest year) and +100 (in the warmest). These two indices are then averaged to produce the Warm-and-Dry Index, which could run from –100 (if the coolest year were also the wettest) to +100 (if the warmest year were also the driest). Results of this index along with mean monthly temperature and rainfall data (for Liawenee and Meander areas) were compared with change in species health to investigate the possibility of a correlation between weather conditions and plant health.

Monitoring Plant Health

Seven dieback sites in the Pine Lake area (fig. 1) were identified for monitoring based on deaths, general discolouration and foliage loss occurring in both *A. cupressoides* and a range of understorey species. Two additional sites (Warners Track and Duncansons Rivulet) with similar floristic and geomorphic characteristics, where plants showed no symptoms of dieback, were chosen as controls. A summary of site descriptions is given in table 1. A summary of species monitored at each site, and presence of dieback symptoms, is included in the appendix.

TABLE 1
Site descriptions

Site (AMG coordinates)	Description
Pine Lake Boardwalk (475500 5378600)	Blockstream. Adjacent to Pine Lake. Overstorey *Athrotaxis cupressoides*. Understorey alpine shrubland.
Western Pine Lake (475000 5378900)	Blockstream. Adjacent to Pine Lake. Overstorey *A. cupressoides*. Understorey alpine shrubland.
Upper Mickeys Creek (474300 5376800)	Upper limit of catchment. Thin peat overlay over blockstream. Overstorey alpine shrubland. Understorey sedges.
Lower Mickeys Creek (475800 5375600)	Blockstream. Streamside. Overstorey *A. cupressoides*. Understorey alpine shrubland.
Half Moon East (476200 5377400)	Peat overlay over blockstream. Fringing *A. cupressoides*. Understorey alpine shrubland.
Half Moon West (475800 5377100)	Blockstream. Fringing *A. cupressoides* and *Phyllocladus asplenifolius*. Understorey alpine shrubland.
Breona Lookout (475500 5375200)	Peat layer overlying blockstream. Alpine shrubland with understorey of sedges and grasses.
Warners Track (Control) (474500 5379400)	Top of catchment, located on saddle. Overstorey alpine shrubland. Understorey is low shrubs and rocky.
Duncansons Rivulet (Control) (473500 5378200)	Peat overlying blockstream. Streamside. Overstorey is fringing *A. cupressoides* and understorey of alpine shrubland.

TABLE 2
Ranking system for recording plant health

Score	Description
0	No signs of plant stress
1	Some discolouration of plant tips
2	General discolouration and "thinning" of foliage
3	Major loss of foliage cover
4	Dead

A total of 530 plants from 15 species were individually tagged. Plastic numbered tags were used to withstand harsh weather conditions. Mapping of tagged plants revealed there was geographical clumping of some plant species. Plant health assessments were made independently by teams of two people using a ranking system that incorporated foliage discolouration and foliage loss, ranging from very healthy (0) to dead (4) (table 2). Each plant was also scored with a (+) or (–) to indicate presence or absence of new growth. Individual plants with health scores of 1 or 2 were preferentially selected for tagging in order to monitor health changes in both negative and positive directions.

Initial assessments were conducted in December 1994. Monitoring at all sites commenced in April 1995 and was completed in April 1999. Sites were monitored twice each year, in March/April (after active growing period) and October (after winter dormant period).

Results obtained from aggregated species data were examined to assess possible trends in temporal change. Changes in species health scores were also tested against rainfall and temperature data and the "warm-and-dry" index, in order to examine any relationship between trends in weather conditions and the onset and progression of disease symptoms.

RESULTS

Observation of Dieback Symptoms

Only symptoms of dieback were monitored, as a causal relationship for the dieback had not been established and investigation of the cause was the subject of a separate study (Chilvers 1998, Mohammed & Shanahan 2000). At Pine Lake, dieback symptoms were observed across a range of plant species. Symptoms were typically chlorosis and anthocyanescence (yellowing and reddening of the leaves respectively) and crown dieback, commonly leading to death in plants belonging to the Proteaceae, Rutaceae, Winteraceae, Cupressaceae and Epacridaceae. Dieback was locally epidemic, demonstrating a distinct temporal sequence of dieback symptoms in the direction of water movement (along drainage lines).

Fifteen species appeared stressed (evidenced by chlorosis and/or crown dieback) or dying. Of these *A. cupressoides, Richea scoparia, Boronia citriodora, Orites acicularis, O. revoluta* and *Tasmannia lanceolata* were most affected.

While all reports of dieback from alpine areas outside the Quarantine Area were investigated, no other site displayed dieback symptoms similar to the Pine Lake area. Patches of dieback in pencil pines and conifer shrub communities were recorded in several mountain areas of central and southwestern Tasmania; however, some of these additional dieback sites have been associated with a stem canker (Yuan *et al.* 2000). Dieback has also been recorded as occurring at a number of locations in the Halfmoon and Mickeys Creek catchments.

Climate Analysis

There were no major climatic trends that could be correlated with the incidence of dieback at Pine Lake. Both temperature and rainfall fluctuate from one extreme to another from year

to year, with no apparent pattern between months or years and no correlation between drought and the onset of disease (fig. 2). The "warm-and-dry index" developed by the Bureau of Meteorology (fig. 3) shows extremes in temperature and rainfall for individual months. The warm, wet spring and summer of 1998 coincided with a general improvement in health at both control and non-control sites for all species. Figure 4 demonstrates the absence of a strong correlation between weather conditions and changes in health scores of plants at the major sites.

Monitoring Plant Health

Data collected from all dieback sites (Upper Mickeys Creek, Lower Mickeys Creek, Pine Lake Boardwalk, Western Pine Lake) were combined and frequency histograms were plotted to show distribution of health scores. This analysis showed that between 1994 and April 1999 the number of plants with health scores greater than 0 (therefore not healthy) decreased for some species, indicating an improvement in plant health over the monitoring period (fig. 5a). The results suggest a substantial improvement in the health of *O. acicularis, T. lanceolata, R. scoparia* and *R. sprengelioides* individuals.

There was a high percentage of unhealthy *A. cupressoides* at the commencement of monitoring at both control and non-control sites. This species appears to have recovered over the four-year monitoring period. Improvement in plant health is substantially greater at control compared with dieback sites (fig. 5b). By 1999, 75% of scored *A. cupressoides* were in Class 0, compared with only 25% in 1995. There was no significant change in the recorded health of other species.

Species data from all sites were combined into two groups (control and dieback sites) to assess changes in health scores over time. Changes in the health of the seven dominant plant species in the area were examined. No discernible pattern appears in health scores, with only minor changes in health scores during the monitoring period. Species data was then collated into sites to examine health trends.

Frequency of health scores (combined species) for each site were calculated and are presented in table 3. Higher numbers of plants were monitored at Pine Lake Boardwalk (table 4) and Western Pine Lake (table 5) allowing assessment of the dominant species. While many species were tagged, the low numbers of individuals of each species at sites has resulted in us assessing the health of each site by aggregating species scores.

Dieback Sites

Pine Lake Boardwalk

Overall species health at this site was monitored through health scores of all species (aggregated). A number of plants improved in health while an equal number of individuals died over this period (table 4).

Initial surveys in December 1994 recorded a total of 23 (out of 28 tagged trees) *A. cupressoides* (pencil pine) showing symptoms of dieback. By 1995, all individuals showed symptoms of dieback. Recent monitoring indicates that there has been little recovery in the pencil pines, with 28 individuals recorded as showing symptoms in 1999. Monitoring of *A. cupressoides* shows that the majority of individuals are in class 2 (general discolouration and thinning).

There was some decline in the health of *R. scoparia* by 1999, no recovery and no deaths. The analysis of health scores for *T. lanceolata* shows that there was an increase in healthy plants. *O. acicularis* showed an increase in the number of both healthy and dead plants over time (table 4).

Western Pine Lake

Distribution of combined species health scores of the four dominant species (*A. cupressoides, R. scoparia, T. lanceolata* and *O. acicularis*) for this site showed a general improvement in plant health (table 3).

Monitoring of *A. cupressoides* showed a general improvement in health over time. Only small numbers of individuals of other species (*R. sprengelioides, Bellendena montana* and *Boronia citriodora*) were present at this site, but the general trend is for an improvement in health (table 5).

Upper Mickeys Creek

While only a small number of individuals of each species are tagged at this site, there has been a general improvement in health over time in the 63 tagged individuals (table 3).

Lower Mickeys Creek

A summary of health scores for this site showed that, while there was an increase in the number of healthy plants over time, there was also a substantial increase in the number of dead plants (table 3).

Half Moon East

Summaries of health scores showed that *A. cupressoides* again was the most susceptible species, with nine out of ten tagged individuals showing symptoms of dieback by 1999. For other species at this site the general trend was an increase in healthy plants with only one death (table 3).

Half Moon West

The trend for all species at this site was a general improvement in health over time, with no mortality (table 3).

Breona Lookout

The trend for all species at this site was a general improvement in health over time, with two mortalities (table 3).

Control Sites

Warners Track

There has been an increase in the number of healthy plants over time at this site, with two mortalities (table 3).

Duncansons Rivulet

There was a marked increase in mortality at this site over time (table 3), due to the impacts of native animal browsing (table 6).

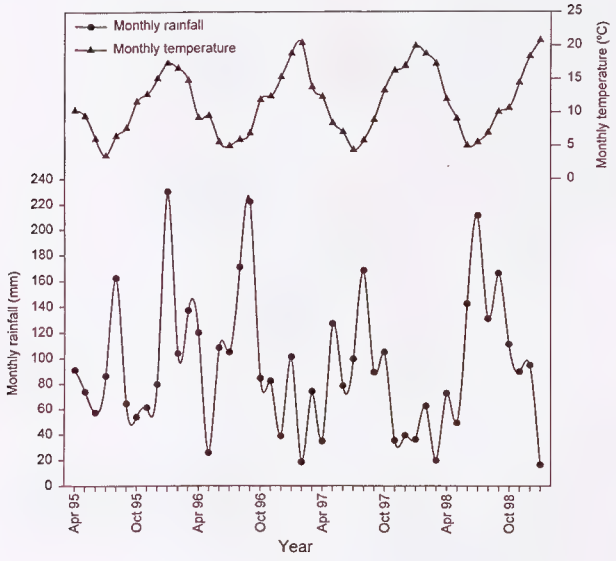

FIG. 2 — Mean monthly temperature and rainfall for the Liawenee weather station, April 1995 to January 1999. Data from Bureau of Meteorology.

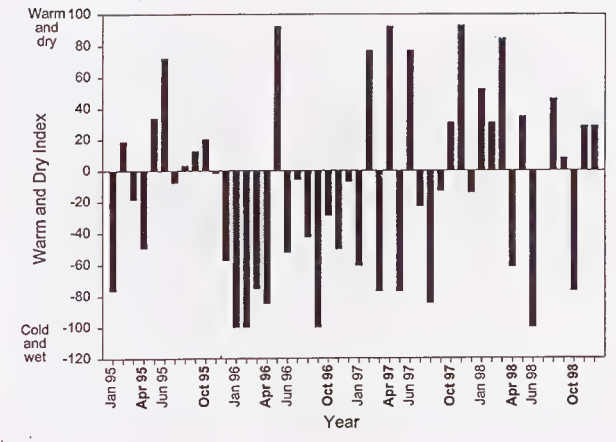

FIG. 3 — Warm-and-dry index (calculated by the Bureau of Meteorology, Barnes-Keoghan 1999) for the months during which sites were monitored (indicated by bold type).

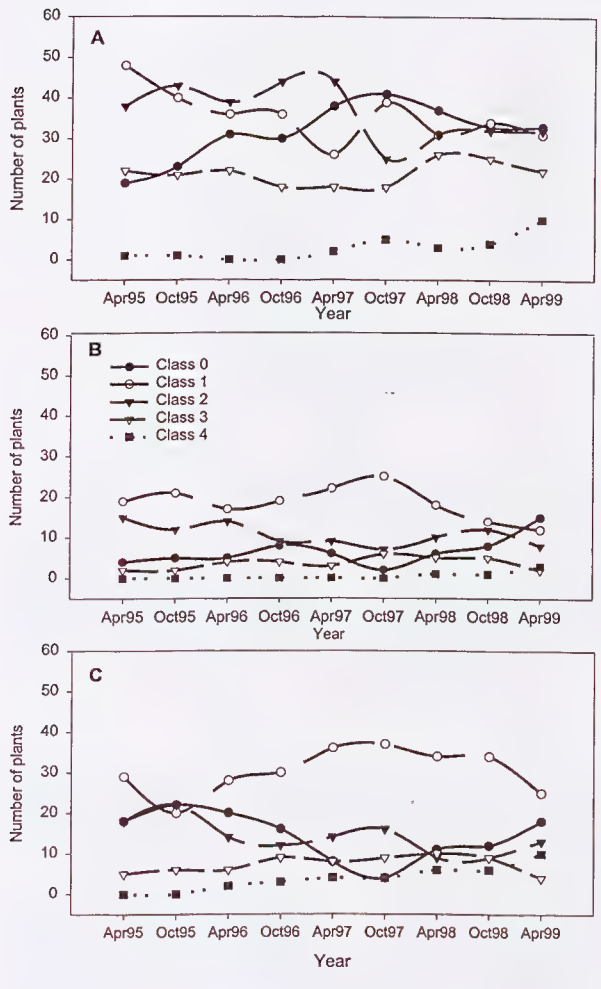

FIG. 4 — Health scores at major monitoring sites (A) Pine Lake, (B) Western Pine Lake and (C) Duncansons Rivulet at each monitoring date. See table 2 for key to health classes.

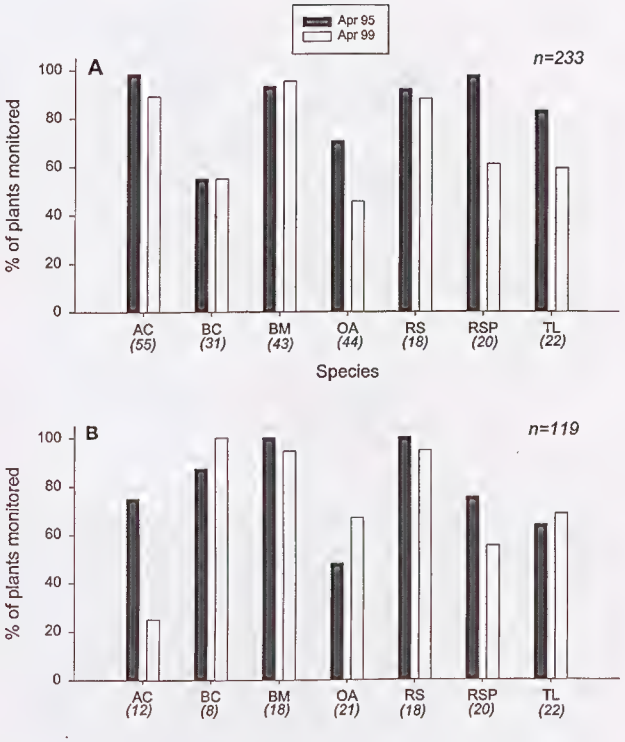

FIG. 5 — Percentage of total plants monitored (A) dieback sites and (B) control sites with health scores not class 0. Number of individuals in each species group is indicated in brackets on the category axis. Key to species: AC, Athrotaxis cupressoides*; BC,* Boronia citriodora*; BM,* Bellendena montana*; OA,* Orites acicularis*; RS,* Richea scoparia*; RSP,* R. sprengelioides*; TL,* Tasmannia lanceolata.

TABLE 3
Plant health scores at all sites in April 1995 and April 1999

		Frequency of health scores*					
Site	Year	0	1	2	3	4	Total
Pine Lake Boardwalk	1995	19	48	38	22	1	128
	1999	31	30	32	22	13	128
	Change	*+12*	*-18*	*-6*	*0*	*+12*	
Western Pine Lake	1995	4	19	15	2	0	40
	1999	15	12	8	2	3	40
	Change	*+11*	*-7*	*-7*	*0*	*+3*	
Upper Mickeys Creek	1995	6	25	22	10	0	63
	1999	14	26	11	9	3	63
	Change	*+8*	*+1*	*-11*	*-1*	*+3*	
Lower Mickeys Creek	1995	15	36	27	11	1	90
	1999	27	23	19	10	11	90
	Change	*+12*	*-13*	*-8*	*-1*	*+10*	
Half Moon East	1995	25	19	10	4	0	58
	1999	33	10	9	5	1	58
	Change	*+8*	*-9*	*-1*	*+1*	*+1*	
Half Moon West	1995	20	12	5	0	0	37
	1999	27	8	2	0	0	37
	Change	*+7*	*-4*	*-3*	*0*	*0*	
Breona	1995	2	7	7	4	0	20
	1999	6	7	3	2	2	20
	Change	*+4*	*0*	*-4*	*-2*	*+2*	
Warners Track	1995	11	14	21	5	0	51
	1999	16	21	11	1	2	51
	Change	*+5*	*+7*	*-10*	*-4*	*+2*	
Duncansons Rivulet	1995	18	30	18	5	0	71
	1999	19	25	13	4	10	71
	Change	*+1*	*-5*	*-5*	*-1*	*+10*	

* Change in health scores shown as + (increase) or – (decrease) in change column. See table 2 for key to health scores.

TABLE 4
Frequency of health scores for major species at Pine Lake Boardwalk

		Frequency of health scores*					
Species	Year	0	1	2	3	4	Total
Athrotaxis cupressoides	1995	0	6	18	4	0	28
	1999	0	8	13	7	0	28
	Change	*0*	*+2*	*-5*	*+3*	*0*	
Richea scoparia	1995	4	12	8	4	0	28
	1999	2	10	13	3	0	28
	Change	*-2*	*-13*	*+5*	*-1*	*0*	
Tasmannia lanceolata	1995	5	14	3	7	1	30
	1999	14	3	4	4	5	30
	Change	*+9*	*-11*	*+1*	*-3*	*+4*	
Orites acicularis	1995	3	7	3	5	0	18
	1999	7	3	0	4	4	18
	Change	*+4*	*-4*	*-3*	*-1*	*+4*	

* See table 2 for key to health scores.

TABLE 5
Frequency of health scores for major species at Western Pine Lake

Species	Year	Frequency of health scores* 0	1	2	3	4	Total
Athrotaxis cupressoides	1995	1	4	4	1	0	10
	1999	5	2	2	1	0	10
	Change	*+4*	*-2*	*-2*	*0*	*0*	
Richea scoparia	1995	0	3	3	0	0	6
	1999	1	4	1	0	0	6
	Change	*+1*	*+1*	*-2*	*0*	*0*	
Tasmannia lanceolata	1995	1	3	1	0	0	5
	1999	2	1	2	0	0	5
	Change	*+1*	*-2*	*+1*	*0*	*0*	
Orites acicularis	1995	0	3	2	0	0	5
	1999	4	1	0	0	0	5
	Change	*+4*	*-2*	*-2*	*0*	*0*	

* See table 2 for key to health scores.

TABLE 6
Number of plants browsed at each site

Site	No. plants browsed	Total no. plants	Percentage of total plants
Duncansons Rivulet	29	72	40.3
Western Pine Lake	9	40	22.5
Breona	3	20	15.0
Lower Mickeys Creek	7	92	7.6
Half Moon East	2	59	3.4
Upper Mickeys Creek	2	64	3.1
Pine Lake Boardwalk	1	133	0.8
Half Moon West	0	37	0.0
Warners Track	0	51	0.0

Browsing Effects

Monitoring results have been influenced by grazing to varying degrees. Table 6 demonstrates the different grazing effects at each site, with much greater grazing intensity (40%) occurring at the Duncansons Rivulet control site.

DISCUSSION

Initially, our greatest concern was the long-term floristic impact on affected alpine communities, particularly the development of dieback in the endemic native conifer, *A. cupressoides*. *A. cupressoides* is slow to mature, long-lived, and an infrequent regenerator with a poor seed-dispersal mechanism. Management actions were taken in accordance with the response plan (Rudman & Whinam 1995), with our aims being quarantine, impact monitoring, investigation of potential causes and subsequent course of action. A project was funded to provide information on the cause and mode of action of dieback in alpine heath and conifer communities, and to verify the identification and pathogenicity of potential pathogens present at diseased sites. An evaluation of the threats posed by *Phytophthora* "Pine Lake" or other pathogens to native plant flora and economically important plants has been made (Chilvers 1998, Mohammed & Shanahan 2000).

Action was taken to minimise the potential for spread of putative pathogens isolated from the diseased area until the status of these organisms is known. To help prevent spread of *Phytophthora* "Pine Lake", the catchments of Halfmoon and Mickeys Creek were declared a Quarantine Area and a Restricted Area under the *Quarantine Act* 1908, with fences constructed at potential lay-by locations along the highway.

The Department of Infrastructure, Energy and Resources (DIER) extended the sealing of the Lake Highway a further 3 km through the quarantine area to minimise movement of road gravels. DIER also stabilised batters to reduce silt loading on adjacent vegetation to minimise adverse impacts on dieback areas.

Monitoring of dieback symptoms in the Pine Lake area was complicated by factors operating over a wide area. In the initial (November 1994) spring/summer monitoring period, an unseasonally heavy, late snow cover was observed at the dieback area. Frost burning was seen on plants such

as *T. lanceolata* and *N. cunninghamii* in spring, and snow caused stem breakage of *O. acicularis* and *R. scoparia.* Patchy dieback of branch tips on the crowns of *A. cupressoides* was observed to be associated with periods of high temperature and not related to soil moisture levels. Surviving foliage maintained its healthy condition. Browning-off in *B. citriodora* and *O. acicularis* was also observed. These stresses were also evident in other alpine and subalpine communities in central and northern regions of Tasmania and at Mt Field National Park in the south. These damage symptoms could be distinguished in the field from the broad floristic signature and patterning of dieback occurring at Pine Lake. While these climatic events obviously were regionally significant, pine stands immediately adjacent to the dieback areas did not show the same symptoms and deaths, suggesting other factors were contributing to the dieback. Native animal browsing has also confounded monitoring results.

It is likely that the dieback is the result of a combination of factors. As a result of this, it is only possible for us to monitor a change in plant health at the sites, comparing control to dieback sites without speculation as to a single cause of the dieback. In the case of Pine Lake dieback, the absence of a proven causal agent and the capacity to reliably isolate it made the process of monitoring dieback difficult. The inclusion of sites for monitoring was by necessity subjective, and monitoring the progress of symptom development and distribution of potential pathogens was not possible within this project. Improvement of these techniques will enable ecological monitoring to be in place early in dieback events, enabling a better indication of dieback progression and impact.

Following identification of possible dieback sites, there are still a number of problems encountered. Sample size is restricted by the labour intensity of monitoring and the sheer practicality of tagging large numbers of plants. Comparison of dieback effects on different species is limited by localised occurrence (i.e. species do not occur at all sites) and by species clumping at sites. These factors make it impossible to achieve an equal sample size for each species at all sites. A limited sample size increases the risk that dieback symptoms will not be detected in that species during the monitoring period.

Monitoring results over the past five years indicate that the impact on the pines has been localised, without significant community structural change. Such structural change is a feature recorded at other disease sites (Weste 1994, Wills 1992). There was no significant decline in health of other species at the dieback sites. No obvious trends or correlation with climatic triggers were evident.

Species health assessments at the control site show an increase in mortality at the end of the monitoring period — a feature not evident in the disease sites. This can be associated with our visual observation of increased browsing damage at the control sites during this time.

While extreme variations in temperature and precipitation occurred on both monthly and yearly time-scales during the monitoring period, no patterns in the weather data were discerned, and there was no discernible correlation between these extremes and plant health. Where pathogens are present, dieback may be dependent on a suite of environmental and host plant conditions to cause disease (Wardlaw & Palzer 1988). Improvement in plant health in the dieback sites indicates the factors that have been interacting are no longer producing an environment conducive to a decline in plant health.

FUTURE MANAGEMENT

Any new reports of dieback in subalpine communities will continue to be investigated to increase our understanding of the patterns of dieback and help identify causes, enabling early action on any new outbreaks that may be discovered. Lower intensity ecological monitoring will be continued in target areas.

Four years of ecological monitoring and pathology results suggest that the scale and intensity of the dieback may not be as severe as initially anticipated; however, the use of the precautionary principle has enabled effective management of a potentially serious environmental threat. At its worst, this situation could have resulted in local extinctions of species of conservation significance at the limits of their range (e.g. *A. cupressoides*) and an alteration in alpine community structure. It was recognised that quarantine at an early stage was going to be the most strategic management action until management questions could be addressed.

ACKNOWLEDGEMENTS

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(accepted 25 June 2001)

APPENDIX

Species monitored and dieback symptoms recorded at each site

	Symptoms	PLB	WPL	HMW	HME	BRE	UPMK	LMK	DRVT	WAR
Athrotaxis cupressoides	chlorosis dieback	•	•	•	•		•	•	•	
Richea scoparia	chlorosis dieback	•	•	•	•		•	•	•	•
R. sprengelioides	chlorosis		•		•	•	•		•	
Boronia citriodora	chlorosis dieback	•	•	•			•	•	•	
Tasmannia lanceolata	chlorosis dieback	•	•	•	•	•	•	•	•	•
Orites acicularis	chlorosis dieback	•	•	•	•		•	•	•	•
O. revoluta	dieback	•		•				•		
Bellendena montana	chlorosis	•	•		•	•	•	•	•	•
Telopea truncata	chlorosis	•								
Epacris serpyllifolia	chlorosis dieback						•			
Cyathodes glauca	chlorosis dieback									
Baeckea gunniana	chlorosis			•					•	
Phyllocladus aspleniifolius	chlorosis			•						

PLB = Pine Lake Boardwalk; WPL = Western Pine Lake; HMW = Half Moon West; HME = Half Moon East; BRE = Breona Lookout; UPMK = Upper Mickeys Creek; LMK = Lower Mickeys Creek; DRVT = Duncansons Rivulet; WAR = Warners Track.

EUCALYPTUS SPP. POLLEN TRANSPORT ACROSS LIAWENEE MOOR, ON THE CENTRAL PLATEAU OF TASMANIA

by P.W. Shimeld and E.A. Colhoun

(with one table, three text-figures and one plate)

SHIMELD, P.W. & COLHOUN, E.A., 2001 (31:xii): *Eucalyptus* spp. pollen transport across Liawenee Moor, on the Central Plateau of Tasmania. *Pap. Proc. R. Soc. Tasm.* 135: 51–55. ISSN 0080–4703. School of Geosciences, University of Newcastle, Callaghan, NSW, Australia 2308.

Investigation of *Eucalyptus* spp. pollen transport modes on Liawenee Moor in Tasmania revealed that it is possible to separate woodland areas from areas of moor and heath vegetation. While most *Eucalyptus* spp. pollen is deposited locally, a relatively small component is distributed across treeless areas, where it behaves in a manner similar to the long-distance transported (LDT) pollen of rainforest and alpine conifer taxa. When deposited into lakes, the *Eucalyptus* spp. component of the terrestrial pollen is increased compared with local pollen. Knowledge of the percentage *Eucalyptus* spp. pollen values from extant vegetation communities and the LDT components of *Eucalyptus* spp. and rainforest–alpine conifer taxa is useful for palaeoecological interpretation of vegetation history from lake sediment cores.

Applied to the 8000-year-long Camerons Lagoon record, the study confirms the treeless character of Liawenee Moor during the Holocene. The evidence indicates that the moorland has altered from grassy to heath, due to the impacts of grazing and burning associated with European pastoral practices, but that the boundaries between the moor and adjacent woodlands have remained stable.

Key Words. ***Eucalyptus*, pollen transport, pollen deposition, Holocene, Tasmania.**

INTRODUCTION

This paper reports the results of a study of the surface distribution of *Eucalyptus* spp. pollen at a site on the eastern Central Plateau of Tasmania (fig. 1). The purpose is to examine the transport of pollen from woodland/forest sources into non-forested areas. The results from this study were then applied to the core studied by Thomas & Hope (1994) at Camerons Lagoon on the southern part of the moor.

Liawenee Moor, west of Great Lake, forms an extensive part of the eastern Central Plateau of Tasmania (fig. 2). It is situated between 1000 and 1100 m altitude, and slopes gently towards Great Lake. The moor coincides with the outcrop of Tertiary basalts. The basalt-derived soils are nutrient-rich but poorly drained. It is surrounded to the north, west and south by Jurassic dolerite, which forms the higher parts of the eastern Central Plateau (Tasmanian Department of Mines 1956). Climatically, the moor lies within the drier parts of the Central Plateau. It has a mean annual precipitation of 985 mm and a mean annual temperature of 10.3°C. The dryness is caused by the maritime westerly airflows being stripped of their moisture by the transversely-oriented ranges of western Tasmania and the high areas of the western parts of the Central Plateau. The dominant westerly airflows descending to Liawenee Moor and Great Lake are adiabatically warmed and dried by a foëhn effect.

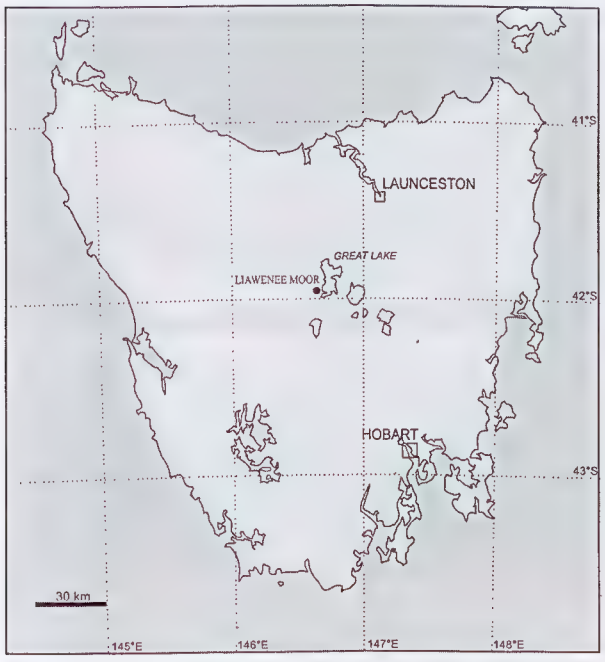

FIG. 1 — Location of Liawenee Moor, Tasmania.

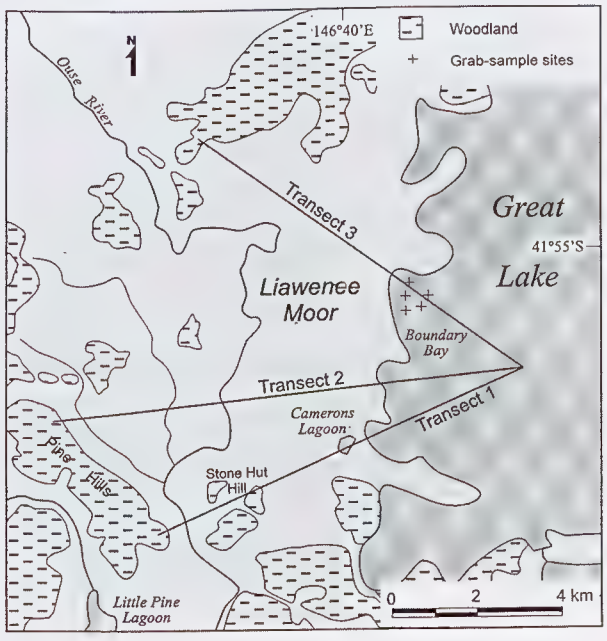

FIG. 2 — Liawenee Moor site map.

The moor is at present treeless. The predominant vegetation consists almost entirely of shrub-steppe dominated by *Helichrysum hookerii* with *Olearia algida, Orites revoluta,* Epacridaceae, *Danthonia* spp. and herbs. The ridges of dolerite surrounding the moor have a cover of *Eucalyptus* woodland with a shrub/grass understorey. The eucalypt species are predominantly *E. delegatensis, E. coccifera* and *E. gunnii* (Thomas & Hope 1994).

Beyond the woodland on the dolerite ridges, the western Central Plateau surface consists of alpine shrub and herb vegetation. There are substantial quantities of the coniferous shrub *Podocarpus lawrenceii,* whose pollen has been transported across Liawenee Moor by westerly winds. These winds also transport pollen of *Nothofagus cunninghami, Phyllocladus asplenifolius* and other rainforest taxa from the valleys to the west. These taxa form the most important components of the discretely identifiable long-distance transported (LDT) component on the moor.

Thomas & Hope (1994) concluded, from studies of pollen taken from Camerons Lagoon near the southern margin (fig. 2), that Liawenee Moor had been treeless throughout most of the middle and late Holocene, and was probably a grassland relic from the last glaciation. The treeless character has been attributed primarily to climatic dryness and poor soil drainage, with modification of the herb and shrub vegetation by Aboriginal burning during the Holocene, and a severe burning and grazing impact with the advent of European settlement (Jackson 1965, 1973, Thomas & Hope 1994).

In this study the pollen rain is separated into three components: pollen produced from local plants on the moorland; pollen from the *Eucalyptus* spp. growing on the dolerite ridges; and the LDT pollen component from the Central Plateau and valleys to the west. By separating these components it is possible to identify what percentages of modern tree pollen are deposited across the moorland and in the bottom sediments of the adjacent parts of Great Lake. Some *Eucalyptus* spp. pollen transport dynamics may then be deduced. These results are applied to the pollen record of Thomas & Hope (1994) to assess the stability of the woodland/moor boundaries and the claim that the moor has remained treeless throughout most of the Holocene.

METHOD

Three transects, focussed on a Mackereth Core site in Great Lake (GR 55GDP774575) (fig. 2), were laid out across Liawenee Moor. These extended into the *Eucalyptus* woodlands on the dolerite ridges (pl. 1). Transect 1 was chosen to intersect Camerons Lagoon, so that surface pollen samples could be compared with the sediment pollen record of Thomas & Hope (1994). It also impinged on Stone Hut Hill and terminated on the southern end of Pine Hills. Transect 2 crossed the south-central part of the moor to the northern end of Pine Hills. Transect 3 crossed the northern part of the moor and terminated on the steep scarp-edge to the northwest.

Sampling frequency along the transects was designed
(a) to examine the distance *Eucalyptus* spp. pollen were transported from the woodlands onto the moor, and
(b) to determine the ratio between the pollen deposited within and adjacent to the source vegetation and that which entered the long-distance pollen rain and was transported across the moor.

PLATE 1
The sharp boundary on the northern margin of Liawenee Moor with the open Eucalyptus *spp. woodlands on the Jurassic dolerite ridge.*

The study is similar to that of Dodson (1983), which concluded that most pollen of insect-pollinated native plants is deposited within 10 m of the source plant. The 0 m sample points on transects were located at the base of the first tree trunks on the sharp woodland–moor boundaries, and the distance between subsequent samples increased exponentially in both directions. Approximately 30 gm-samples of moss were taken at each transect-sample point by integrating nine regularly spaced subsamples within a 4 m^2 plot. Five bottom-sediment grab-samples taken from Boundary Bay in Great Lake represent modern unconsolidated lake sediments (fig. 2).

The moss samples collected from the transects were thoroughly mixed and subsamples of 1 gm were processed for pollen using KOH treatment, sieving at 100 µm, Erdtman's acetolysis and mounting in glycerol following procedures described in Fægri *et al.* (1992). The lake sediments were not sieved but received HF treatment to remove clays.

At least 300 pollen grains of terrestrial taxa were counted for each sample from Liawenee Moor and 150 grains from the Great Lake bottom sediment samples. The pollen was identified using the Tasmanian pollen reference collection (http://www.newcastle.edu.au/department/gg/pol/0Intro.html) in the School of Geosciences, University of Newcastle.

RESULTS AND DISCUSSION

On Liawenee Moor, the pollen analysis revealed that there is a very sharp decrease in the ratio of *Eucalyptus* spp. to total terrestrial pollen from the well-defined woodland edge to the moor. A sharp fall-off in pollen occurs within 6 m, the first inter-sample distance (fig. 3A, C). The effect of a tree 13 m beyond the woodland boundary on Transect 2 (fig. 3B) is clearly visible. On all transects woodland may be defined by >11% *Eucalyptus* to terrestrial pollen, to a high of 70%. Low values within the woodland reflect an outcrop area of bare rock (fig. 3A) and a small block stream (fig. 3C). Samples from the moor give ratios of *Eucalyptus* to terrestrial pollen of <11%, except adjacent to Stone Hut Hill which is an area of open woodland (fig. 3A).

The samples also contain LDT pollen from the alpine and forested regions of the higher parts of the Central Plateau and ranges to the west. Given that these pollen taxa are derived from distant sources, values for this component would be expected to be constant across the study area. The major LDT taxa include the rainforest species *Nothofagus cunninghamii, Phyllocladus asplenifolius, Lagarostrobos franklinii* and the alpine taxon *Podocarpus lawrencii.* In addition, spores of the treeferns *Dicksonia antarctica* and *Cyathea australis,* and pollen of *Pinus* are included in the LDT sum, these taxa not being present on the moor or adjacent ridges. Percentages of LDT terrestrial pollen and spores average 3.1 ± 0.6% for the woodland and 4.5 ± 1.7% for the moor.

The ratio of total *Eucalyptus* spp. pollen to the LDT counts allows the comparison of pollen signatures between the woodland, moor and lake. Within the woodland this ratio varies between 4 and 34:1, but on the moor the ratio is very low and stable, not exceeding 3:1.

The grab samples from Boundary Bay (figs 2, 3D, table 1) show that the percentage of *Eucalyptus* spp. pollen and the LDT component are about twice the moor values. This

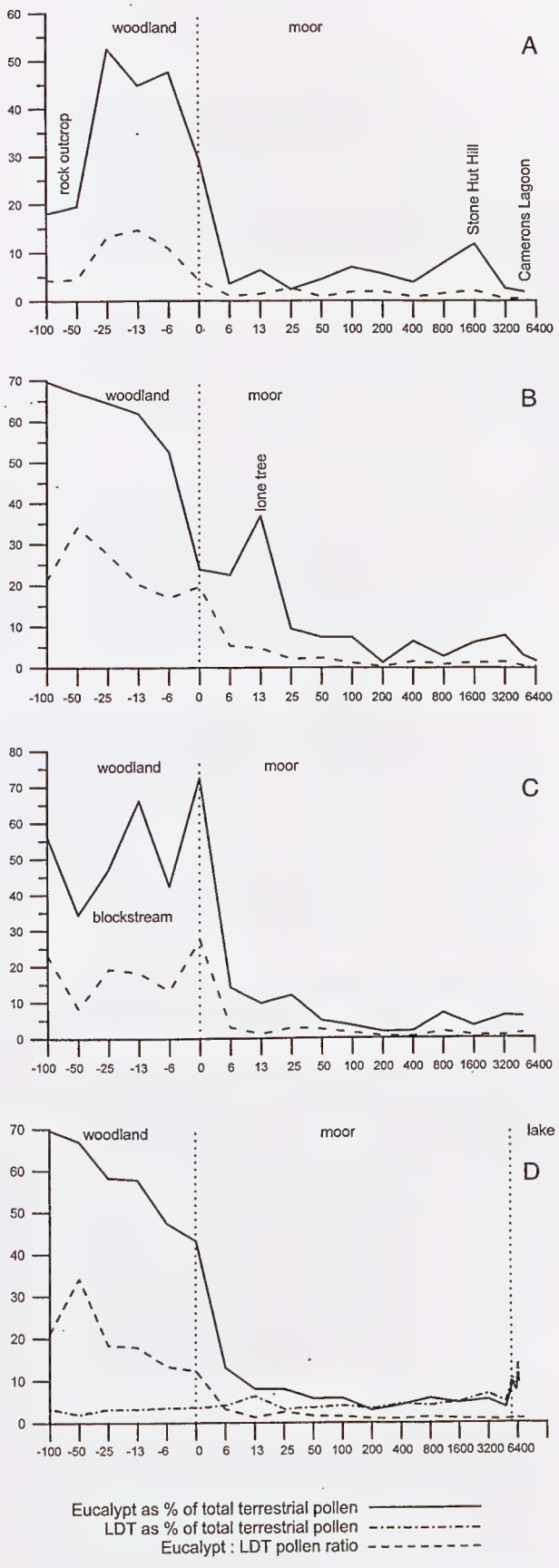

FIG. 3 — Liawenee Moor pollen transport: distance (m) from woodland–moor boundary. (A) transect 1. (B) transect 2. (C) transect 3. (D) averaged transects.

TABLE 1
Summary of environments for Liawenee Moor and Great Lake*

	n	% Eucalyptus ±1σ	% LDT ±1σ	Eucalyptus: LDT ±1σ
Woodland/ forest †	10	60.0 ± 6.4	3.1 ± 0.6	20.5 ± 6.2
Moor ‡	29	5.2 ± 2.8	4.5 ± 1.7	1.3 ± 0.7
Lake bottom	5	9.3 ± 1.5	10.7 ± 2.1	0.9± 0.1

* All transition samples (0–13 m) have been excluded (see figs 3A–D).
† Excluding rock outcrop and open woodland samples.
‡ Excluding Stone Hut Hill sample.

indicates a gross reduction in transport of pollen from local moorland taxa to the lake and a through-carriage of low quantities of both *Eucalyptus* spp. and LDT pollen across the moor. The *Eucalyptus* spp. pollen on the moor and lake have similar concentration patterns to the other LDT pollen taxa. This is also shown by the similar *Eucalyptus*:LDT ratios for the moor and lake.

The increase in *Eucalyptus* spp. pollen to 9.3 ± 1.5% in the Boundary Bay samples compared with the values on Liawenee Moor suggests that if *Eucalyptus* spp. pollen in lake sediments does not exceed this value, then *Eucalyptus* woodland was probably not present as part of the local vegetation. This result is in accord with the conclusion of Thomas & Hope (1994) that values of <15% of fossil *Eucalyptus* spp. pollen in the terrestrial sums at Camerons Lagoon do not substantiate the presence of local *Eucalyptus* woodlands on the moor throughout the mid- to late Holocene.

Results from this study indicate that the <15% of *Eucalyptus* spp. pollen in the sediments of Camerons Lagoon is consistent with treelessness and up to 39% for Poaceae indicates that the moor was very grassy. This suggests that the moor remained a treeless plain after melting of glaciers to the west. Its survival is probably attributable to a combination of factors including reduced rainfall, poor drainage, cold air drainage from the Central Plateau into the upper Ouse Valley, high-nutrient status of the basalt soils and possibly Aboriginal burning (Thomas & Hope 1994, Jackson 1973, Kirkpatrick 1983, Kirkpatrick & Dickinson 1984). Aborigines are known to have occupied the Mersey Valley, 40 km to the northwest, throughout the Holocene (Lourandos 1983).

The uniformity of representation of pollen percentage values for *Eucalyptus* spp. and Poaceae throughout the last 8000 years shows stability of the vegetation not only on the Moor but also of the woodland on the surrounding dolerite ridges. The change to higher values for Asteraceae tubuliflorae, Epacridaceae and Restionaceae at 100 mm depth in the Camerons Lagoon record is consistent with the moor becoming more heathy as a result of the impact of grazing and burning of the mountain grasslands, as indicated by Jackson (1965, 1973).

CONCLUSIONS

Study of pollen transport across Liawenee Moor shows that *Eucalyptus* spp. pollen dominates the total pollen recovered from moss polsters within 6 m (being the first inter-sample distance) of the source vegetation. Beyond 6 m this taxon is a minor component of the total pollen sum. This supports Dodson's (1983) conclusions that the pollen of most native insect-pollinated species is deposited within a few metres of source plants. However, this paper shows that there is also a significant LDT component that can be associated with *Eucalyptus* spp., and it is likely that similar patterns exist for other native species.

Approximately 90% of the pollen deposited in moss samples on Liawenee Moor is derived locally from heath, grass and herb plants. About 5% is LDT pollen from rainforest and alpine taxa west of the study site, and around 5% is *Eucalyptus* spp. pollen derived from the bounding forested dolerite ridges, also transported across the moor as a LDT component.

The doubling in percentages of pollen from both *Eucalyptus* spp. and the LDT rainforest and conifer species in the lake-floor sediments represents reduction in transport of local pollen taxa from the moor. Thus, in this region, values for *Eucalyptus* spp. below about12% (i.e. 9.3 + 2σ, table 1) do not indicate the presence of local woodland or forest.

When the results of this study are applied to the 8000-year Camerons Lagoon record, the treeless character of Liawenee Moor throughout the Holocene, as interpreted by Thomas & Hope (1994), is confirmed. The results also indicate that the boundaries between the forest/woodland vegetation and the moor remained stable during the Holocene. The moor was probably much richer in grassland than at present, the alteration to heathland being a product of European settlement involving grazing and burning, as suggested by Jackson (1973).

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(accepted 10 May 2001)

THE MIENA CIDER GUM, *EUCALYPTUS GUNNII* SUBSP. *DIVARICATA* (MYRTACEAE): A TAXON IN RAPID DECLINE

by B.M. Potts, W.C. Potts and G. Kantvilas

(with three plates)

POTTS, B.M., POTTS, W.C. & KANTVILAS, G., 2001 (31:xii): The Miena cider gum, *Eucalyptus gunnii* subsp. *divaricata* (Myrtaceae): a taxon in rapid decline. *Pap. Proc. R. Soc. Tasm.* 135: 57–61. ISSN 0080–4703. Cooperative Research Centre for Sustainable Production Forestry and School of Plant Science, University of Tasmania, GPO Box 252-55, Hobart, Tasmania, Australia 7001 (BMP); Threatened Species Unit, Department of Primary Industries, Water and Environment, GPO Box 44, Hobart, Tasmania, Australia 7001 (WCP); Tasmanian Herbarium, GPO Box 252-4, Hobart, Tasmania, Australia 7001 (GK).

The new combination *Eucalyptus gunnii* subsp. *divaricata* (McAulay & Brett) B.M.Potts comb. & stat. nov. is introduced for the Miena form of the Tasmanian cider gum *Eucalyptus gunnii* Hook.f., once described as a separate species, *E. divaricata* McAulay & Brett. This subspecies occurs on the Central Plateau of Tasmania, where it intergrades clinally with *E. gunnii* subsp. *gunnii* and *E. archeri*. Core populations of this subspecies are among the most frost-resistant of *E. gunnii* sens. lat., have juvenile foliage of interest for floriculture and have been exploited historically for their sweet sap. However, high mortality of trees in the last decade, coupled with only rare seedling recruitment and poor seed crops, is threatening the long-term survival of this taxon in the wild. *E. gunnii* subsp. *divaricata* qualifies as Endangered under Commonwealth and Tasmanian legislation.

Key Words: cider gum, *Eucalyptus gunnii*, *Eucalyptus archeri*, endangered species, Miena, Tasmania.

INTRODUCTION

The name *Eucalyptus divaricata* McAulay & Brett was introduced by Brett (1938) for an extreme form of *E. gunnii* Hook.f. growing near Miena in the Central Highlands of Tasmania. However, this taxon was subsequently subsumed by taxonomists within *E. gunnii* (Curtis & Morris 1975, Pryor & Johnson 1971, Brooker 2000). It has, however, been shown to be a cline form of *E. gunnii* (Potts & Reid 1985a, b). It is here reinstated as *Eucalyptus gunnii* subsp. *divaricata* (McAulay & Brett) B.M.Potts comb. & stat. nov., a tree of considerable economic and cultural significance. *E. gunnii* sens. lat. is one of the most frost-resistant species of *Eucalyptus* (Davidson & Reid 1985, Cauvin & Potts 1991, Kirkpatrick & Gibson 1998, 1999), and *E. gunnii* subsp. *divaricata* encompasses the most frost-resistant populations (Cauvin & Potts 1991). It is being used in breeding programs overseas where eucalypts are being planted in areas at the limits of cold tolerance for the genus (Potts & Potts 1986). The juvenile foliage of *E. gunnii* is also widely used in floral arrangements both overseas and within Australia; that of the subspecies *divaricata* is most prized by florists because of its durability, glaucousness (Wirthensohn *et al.* 1999) and small, rounded leaves. Aborigines are reported (Plomley 1966) to have collected and drunk the sap from large trees of *E. gunnii* sens. lat. growing in areas that also support *E. gunnii* subsp. *divaricata*. There are also reports of both Aborigines and stockmen drinking the naturally fermented sap, which had an intoxicating effect (Bruce 1857, Plomley 1966); the first report may be the only record of pre-European use of an alcoholic beverage in Australia. The sweet sap produced by the species is also a food source for native insects, birds and marsupials (e.g. Plomley 1966). [In some years the production of manna is copious, presumably following insect browsing of the foliage. The soil under trees then has an almost complete cover of manna pellets. Large flocks of parakeets have been seen in a "drunken" state picking up manna and drinking from pools of sap and damp areas (W. D. Jackson, pers. com. 2001).] The taxon has been the subject of ongoing scientific study of evolutionary processes in Tasmania (Potts 1985, Potts & Reid 1985a,b) and is therefore of educational significance.

TAXONOMY

Eucalyptus gunnii subsp. *divaricata* (McAulay & Brett) B.M.Potts comb. & stat. nov.

Basionym: *Eucalyptus divaricata* McAulay & Brett, *Pap. Proc. Roy. Soc. Tas.* for 1937: 94 (1938).
Lectotype (here designated): Tasmania: Miena, Great Lake, September 1938, *R.G. Brett* (2.221, S3, H130) (HO 16163; Photo 1); isolectotype: (HO 16165).

Description

Small to medium woodland tree, 12–15 m high, often with markedly divaricating branching. Juvenile leaves opposite, glaucous, cordate-orbicular to elliptical, subcrenulate, sessile, 2.5 x 2 cm. Mature leaves green or subglaucous, alternate, petiolate, narrow to broad-lanceolate 4–8 x 1.5–3 cm. Umbels axillary, three-flowered. Peduncles 5–10 mm. Buds sessile to shortly pedicellate, glaucous, obovate to cylindrical, 6–8 x 5 mm. Operculum shorter than calyx tube. Fruit often glaucous, cylindrical to suburceolate; often urceolate when immature, 7–9 x 6 mm. Branchlets covered in a heavy waxy bloom that often extends onto flower buds and young capsules.

Brett (1938) did not formally designate a holotype for his new taxon. However, his specimens, now held in the Tasmanian Herbarium (HO), are well annotated and it is clear which sheets were considered by him to be typical for

PLATE 1
Lectotype of Eucalyptus gunnii *subsp.* divaricata *collected by R.G. Brett in September 1938 from Miena, Great Lake (HO16163).*

the taxon. Accordingly, one of these (HO 16163) is here designated as the lectotype (pl. 1).

Specimens examined

Tasmania: West side of Great Lake, 20 km from Miena, *H.N. Barber* 2536, 15.ii.1953 (HO 16188); Great Lake, *H.N. Barber* 2537, 15.ii.1953 (HO 16248); Bakers Tier, *R.G. Brett*, 15.viii.1935 (HO 16154); Bakers Tier, *R.G. Brett*, 15.viii.1937 (HO 16158); Miena, Great Lake, *R.G. Brett*, 15.ix.1938 (HO 16163 & HO 16165); east side of Great Lake, *M.I.H. Brooker 5750*, 21.xi.1977 (HO 28752); Tods Corner, *A.M. Buchanan 15012*, 9.xii.1997 (HO 323958); Great Lake, *N.T. Burbidge 3440*, 28.i.1949 (HO 16252); Great Lake, *W.M. Curtis*, 28.i.1970 (HO 51578); Lake Highway, at intersection of Tods Corner Road, *F. Duncan 23*, 12.x.1983 (HO 68582); Lake Highway, 53.8 km northwest of Bothwell, southern end of Great Lake, *A.M. Gray 381*, 4.vi.1979 (HO 30186); Barren Tier, Great Lake, *M.J. Hood 18*, 26.iii.s.year (HO 16221); Miena, Shannon Lagoon, *B. Potts*, ii.1990 (HO 511233 to HO 511236 & HO 511239); Great Lake, *L. Rodway*, 15.v.1893 (HO 16183).

DISCUSSION

Eucalyptus gunnii subsp. *divaricata* is phenotypically (Potts & Reid 1985a) and genetically (Potts 1985, Potts & Reid 1985a, Cauvin & Potts 1991) differentiated from other members of the *E. gunnii–E. archeri* complex. Five clinal morphs have been identified in the complex, including *E. gunnii* subsp. *divaricata, E. archeri,* southern *E. gunnii* subsp. *gunnii,* northwestern *E. gunnii* subsp. *gunnii* and localised intermediates between *E. archeri* and *E. gunnii* subsp. *divaricata.*

Eucalyptus gunnii subsp. *divaricata* can be distinguished from *E. gunnii* subsp. *gunnii* by its smaller, broader juvenile and adult leaves, and by a greater degree of glaucousness that extends from both juvenile and adult leaves onto the young stems and often onto flower buds and capsules (Potts & Reid 1985a, b). It has a more cylindrical to sub-urceolate capsule (pl. 1) than the typical companulate or ovoid-truncate capsule of other members of the *E. gunnii–E. archeri* complex (Potts & Reid 1985a). It is also differentiated from *E. gunnii* subsp. *gunnii* by a greater retention of the juvenile foliage (Potts 1985), greater lignotuber development (Potts 1985), an absence of marked oil glands in the juvenile leaves, and by the composition of leaf volatile oils (Li *et al.* 1996) and the surface wax (Li *et al.* 1997). Its leaf volatile oil is dominated by *p*-cymene and spathulenol and contains virtually no 1,8 cineole, the dominant component in five populations of *E. gunnii* subsp. *gunnii* (17–57%) examined. Its leaf waxes also have a higher percentage of β-diketones and triterpenoids and a lower percentage of alkanals. Mature trees of *E. gunnii* subsp. *divaricata* usually have more branched (hence the epithet "*divaricata*"), rounder crowns (pl. 2) than lower-altitude tree forms of *E. gunnii* subsp. *gunnii*, although this feature is likely to be partly a consequence of the more exposed habitat.

Core populations of *E. gunnii* subsp. *divaricata* at Miena and on the western shores of Great Lake are also differentiated by up to 1.5 months in peak flowering time from higher altitude populations of other members of the *E. gunnii–E. archeri* complex and lower altitudes populations of *E. gunnii* subsp. *gunnii* on the Central Plateau (Potts & Reid 1985a). For example, in the 1979–80 and 1980–81 flowering seasons, flowering in the Miena population peaked in December and January, whereas nearby *E. gunnii* subsp. *gunnii* populations in more sheltered, lower altitude sites peaked in February and March. It is not known whether this difference in flowering time has a genetic basis or is environmentally induced. Regardless, such differences appear to be stable across seasons and would act as a barrier to gene flow between the two subspecies when they are in close geographic proximity.

Distribution and Ecology

Eucalyptus gunnii subsp. *divaricata* is a woodland tree adapted to the edges of treeless flats and hollows (often termed "frost hollows") in the general vicinity of Great Lake on the Central Plateau, Tasmania (Jackson 1973, Kirkpatrick & Gibson 1998, 1999). These sites tend to be poorly drained, and exposed to the early morning sun, both of which may accentuate the damaging effects of frost (Davidson & Reid 1987, Close *et al.* 2001). Nevertheless, in winter, these sites tend to be covered by cloud and mist; the ability of *E. gunnii* sens. lat. to tolerate frosts under such wet conditions is believed to have allowed it to dominate high-altitude sites (Potts & Reid 1985b, Kirkpatrick & Gibson 1999).

E. gunnii subsp. *divaricata* is known from several major occurrences in a 40 x 40 kilometre area stretching from

PLATE 2

Typical form of the large E. gunnii *ssp.* divaricata *trees in the Miena population. The specimen Brett used to describe the taxon* E. divaricata *in 1938 is thought to have been near the above tree on the side of the Lake Highway, overlooking Shannon Lagoon near Miena (W.D. Jackson, pers. com.).*

PLATE 3

The western end of the Miena population of E. gunnii *ssp.* divaricata *in 2000. The last decade has seen a major increase in the mortality of these old trees on the Central Plateau. The surviving trees in this population are virtually devoid of seed crops, and established seedlings and saplings are rare (photo T. Jones).*

west of Miena to Interlaken. Key localities are Miena (east of Shannon Lagoon), South Brandum, Jimmys Marsh (Alma Tier), Arthurs Lake, Jacks Marsh (Steppes), St Patricks Plain, north of Lake Echo, and the shores of the southern half of Great Lake. The populations to the immediate south of Great Lake include the stand at Miena, which exhibits the most extreme morphology within the taxon and has been designated as the type locality. This extreme is believed to represent Brett's view of typical *E. divaricata* (W. D. Jackson, pers. comm.). Unfortunately this population has shown the greatest decline, with the authors estimating that more than 60% of the mature trees have died in the last ten years. From this core area, the taxon clinally intergrades into (1) *E. gunnii* subsp. *gunnii* with decreasing altitude to the southeast, (2) a small tree or mallee form on exposed sites at higher altitudes with close affinities to *E. gunnii* subsp. *divaricata*, and (3) the closely related *E. archeri* Maiden & Blakely at the northern end of Great Lake where rainfall is higher (Potts & Reid 1985a, b).

The rapid decline of *E. gunnii* subsp. *divaricata* throughout its geographic range is likely to be due to a combination of factors brought to a head by droughts in this region over the last two decades, and coincides with severe tree decline in the rain shadow east of the Central Plateau, particularly in the Midlands (Neyland 1996, Kirkpatrick *et al.* 2001). It has also been accompanied by significant crown decline (many trees are now regenerating from epicormics) in extensive areas of subalpine forests south and west of Great Lake dominated by *E. delegatensis* and *E. coccifera*. Indeed, in the case of *E. gunnii* subsp. *divaricata*, we may be witnessing an impact of long-term global warming on the Tasmanian eucalypt gene pools — the loss of resistance to extreme frost. There appears to have been a 1.5°C increase in mean daily maximum temperature in this general region between 1945 and 1995 (Kirkpatrick & Gibson 1999). Field trials have also shown that over the last decade climatic conditions near Great Lake have been sufficiently mild to potentially allow an increase in the altitudinal limit of *E. rodwayi* (Kirkpatrick & Gibson 1998, 1999), a species that normally replaces *E. gunnii* on the margins of poorly drained, treeless flats at mid-altitudes on the Central Plateau.

The large trees of *E. gunnii* subsp. *divaricata* are no doubt ancient, and many were already overmature in the late 1970s, with numerous fire scars and moribund branches. The surviving trees are often in poor health, and flower buds or capsules are rarer than in previous decades. When such trees resprout from epicormic buds, the succulent new growth in the upper canopy is often browsed intensively by brushtail possums (*Trichosurus vulpecula*), which favour trees of *Eucalyptus gunnii* sens. lat. (Scott *et al.* in press, Dungey & Potts in press); the browsing may well hasten the death of mature trees. Less eucalypt foliage, more nesting sites in dead trees, and the increase in possum numbers in the Central Highlands following the cessation of the possum fur trade may well increase browsing pressure beyond what the surviving trees can support. The felling of many large, mature trees on the Central Plateau over the last 20 years, when raising the level of Great Lake and clearing roadsides, has compounded the decline in mature *E. gunnii* subsp. *divaricata*. Around Great Lake there is, however, regrowth of coppice and advanced saplings.

The recent high mortality of mature trees is particularly significant, as many stands have very few immature individuals available to replace this mature cohort (pl. 3). Established seedlings are rare, and most surviving saplings appear to be associated with shrubbery. The insolated, open-woodland site occupied by typical *E. gunnii* subsp. *divaricata* (Potts & Reid 1985a; pls 2, 3 present study) is extremely harsh for seedling establishment, due to exposure to both frost and drought (Potts 1985). Over the last century this has been aggravated by browsing pressure from sheep, rabbits and native marsupials, coupled with frequent firing of the vegetation to reduce the shrub component of the vegetation (Jackson 1973, Gibson & Kirkpatrick 1989). Gibson & Kirkpatrick (1989) noted that, if summer grazing were not removed or reduced dramatically at Miena, the site would inevitably change from woodland to grassland at the end of the life span of the existing trees.

The canopy seed crops have been dramatically reduced with either the death of the mature trees or severe loss of the reproductive capacity of surviving trees. The threat to the regeneration potential of these stands is further exacerbated by the increased isolation of flowering trees, which is likely to increase the rate of self-fertilisation in the open-pollinated seed crop and hence reduce the fitness of the subsequent seedling cohort (Borralho & Potts 1996, Hardner *et al.* 1996). *Eucalyptus gunnii* sens lat. seedlings derived from self-fertilisation have poorer vigour and survival than seedlings derived from unrelated crossing (Potts *et al.* 1987).

Conservation Status

Eucalyptus gunnii subsp. *divaricata* qualifies as Endangered under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* and the Tasmanian *Threatened Species Protection Act 1995*. Qualifying criteria are a restricted distribution; the number of reproductive individuals being possibly fewer than 2500; a continuing decline in the number of mature individuals; and a decline of greater than 20% in the total population over five years. At the time of submission of this paper the taxon has been nominated formally for listing under Commonwealth and Tasmanian legislation.

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(accepted 29 October 2001)

INTRUSIVE RELATIONSHIPS OF GRANITE AND DOLERITE AT LAGUNTA CREEK, FREYCINET PENINSULA

by John L. Everard

(with one table, five text-figures and eight plates)

EVERARD, J.L., 2001 (31:xii): Intrusive relationships of granite and dolerite at Lagunta Creek, Freycinet Peninsula. *Pap. Proc. R. Soc. Tasm.* 135: 63–74. ISSN 0080–4703. 386 Howden Road, Howden, Tasmania, Australia 7054.

Coastal exposures immediately south of the mouth of Lagunta Creek, Freycinet Peninsula, eastern Tasmania, illustrate the temporal and spatial relationships between various Devonian granites and a dolerite dyke. The oldest granite, an equigranular grey hornblende-biotite adamellite containing abundant mafic enclaves, was intruded by a more felsic, equigranular to variably porphyritic or seriate pink alkali feldspar granite, and associated aplite, leucogranite and pegmatite dykes. Field relationships indicate brittle fracture and stoping of the adamellite during dilational emplacement of the pink granite. Minor bodies of granite porphyry are also younger than the adamellite. A dolerite dyke, of hawaiitic composition and containing plagioclase megacrysts, intrudes the adamellite and also crosscuts the aplite and leucogranite dykes, and is the youngest phase.

The granites are metaluminous to very weakly peraluminous, and are classified as I-types on both mineralogical and geochemical criteria. The adamellite is unfractionated and chemically reduced, and, together with similar rocks at Wineglass Bay and Cape Tourville, constitutes the Bluestone Bay Suite, which is geochemically distinct from, and younger than, other eastern Tasmanian granodiorite/adamellites. In contrast, both the pink granite and, to a lesser extent, the granite porphyry are fractionated and locally magnetite-bearing. Fractionation has resulted in high Rb, Y, Th and Pb and low P, Sr and Ba. The dolerite dyke, despite its alkalic major element chemistry, is depleted in Nb like some other granite-associated mafic rocks in the southern Lachlan Fold Belt.

Key Words: granite, dolerite, enclaves, Devonian, Freycinet Peninsula, Tasmania

INTRODUCTION

There are few studies of the Devonian granites that form most of Freycinet Peninsula (fig. 1), and only the southern tip has been systematically mapped by the Tasmanian Geological Survey (K. D. Corbett, pers. comm.). The inferred Ordovician–Early Devonian Mathinna Group country rocks occur only as a small area near Bluestone Bay (Cocker 1977). A major north–south trending fault, downthrown to the west, transects the west coast of the Peninsula near Hepburn Point and Weatherhead Point. Jurassic dolerite lies west of the fault, apart from small areas of Triassic sandstone west of Bryans Bay. The fault continues southward to bisect Schouten Island, the eastern half of which is composed of granitic rocks (Bacon & Corbett 1984).

Foreshore exposures near Coles Bay were examined in detail by Groves (1965), who also produced a sketch map of the Hazards area. He described the dominant rock type as a variably porphyritic "red adamellite", associated with microadamellite and quartz feldspar porphyry dykes and minor pegmatite. This was thought to be younger than an even-grained "grey adamellite with xenoliths", noted in the Bluestone Bay and Wineglass Bay areas.

A more detailed map of the Hazards Range, accompanied by field and petrological descriptions of the various granite types, was provided by Dunderdale (1989). She showed that most (> 90%) of this area consists of "red microcline granite", locally yellow due to hydrothermal alteration, with minor intrusions of quartz feldspar porphyry and microgranite. Small bodies of granodiorite at Wineglass Bay and "white granite" southeast of Fleurieu Point were both shown to be older intrusions.

McDougall & Leggo (1965) obtained a Rb/Sr age of 375 Ma (now recalculated to 368 Ma using new decay constants) from biotite in a "leucocratic pink granite" from the quarry south of Coles Bay. This was considered a minimum age. K/Ar dates from the same biotite yielded slightly younger ages of 347 to 355 (± 10) Ma (now 353 to 361 Ma) which were attributed to resetting. A whole rock-mineral Rb/Sr isochron gave a younger age of 353 Ma (now 345 Ma), which was discounted due to the likelihood of mobility of radiogenic Sr in feldspars.

Cocker (1977) also conducted a Rb/Sr study, and provided a simple map, of granite and granodiorite in the Coles Bay–Bluestone Bay area. Probably the most reliable dates (recalculated using new decay constants) are from biotites: 370.8 (± 3) Ma from a pink felsic granite and 372.8 (± 3) Ma from a granodiorite, both from north of Sleepy Bay. The data are consistent with those of McDougall & Leggo (1965) and suggest that pink felsic granite was intruded shortly after the granodiorite in the late Middle Devonian (Givetian).

This paper describes the excellent coastal exposures of granite which, interrupted by small sandy beaches, extend from Lagunta Creek (at the southern end of Hazards Beach) for 3.5 km SSW to Cooks Beach. The most varied geology is within 1 km of Lagunta Creek (fig. 2).

ADAMELLITE/GRANODIORITE

The oldest granite in the area, well exposed as the country rock to the dolerite dyke at the mouth of Lagunta Creek (pl. 1), is a grey to white, medium- to fine- grained (1–3 mm) equigranular and unfoliated adamellite, in which scattered flakes of shiny black to dark green biotite and dull steel-grey hornblende are readily visible in hand specimen. It crops out along the shore southward for about 1 km, but is intruded, in places intensely, by other rock types, as described below.

The adamellite contains conspicuous and numerous (1–2% of outcrop) dark-grey to grey-green, finer grained (0.5–2 mm) mafic enclaves (pls 2, 3). They are typically

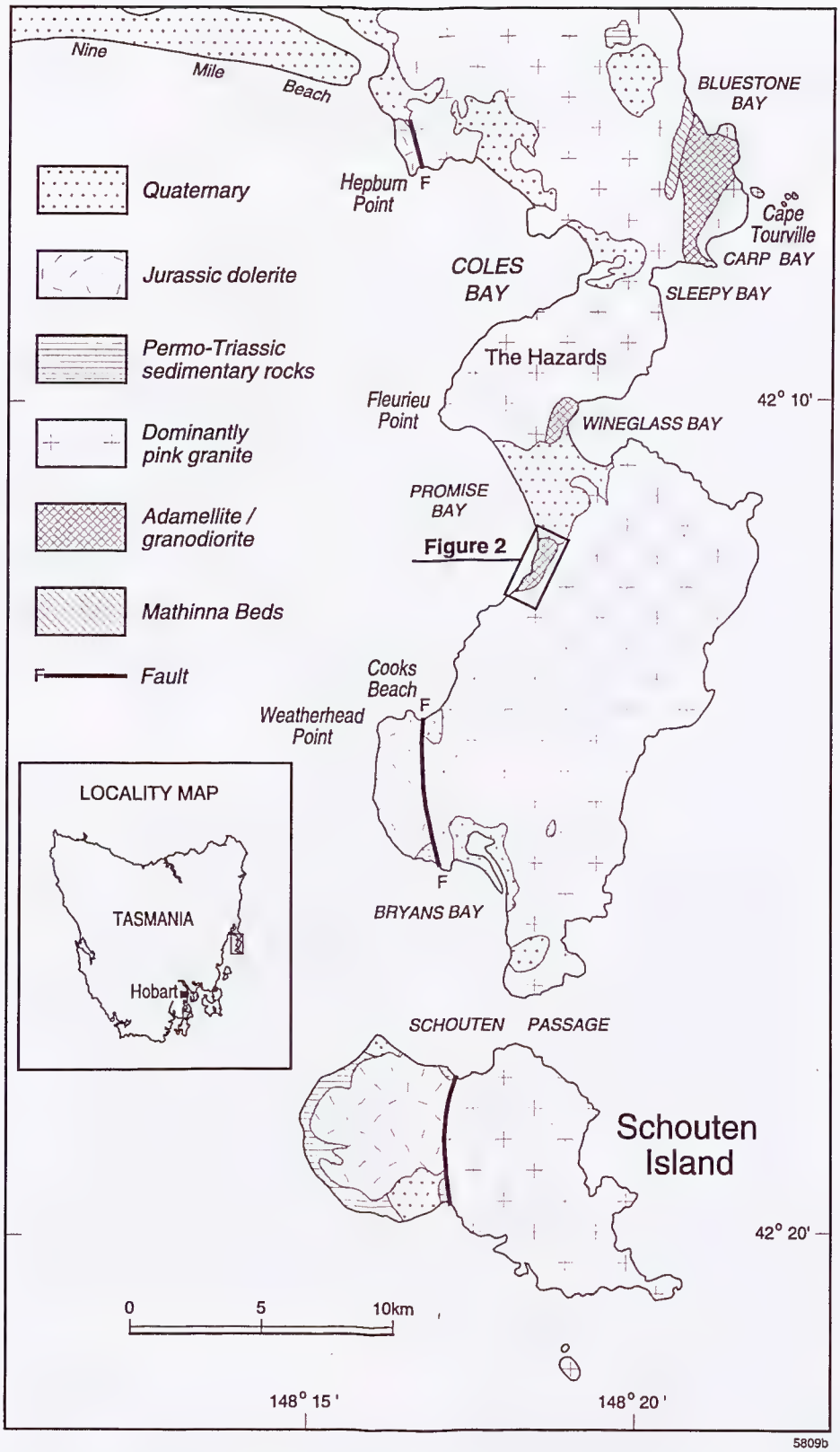

FIG. 1 — Simplified geology of Freycinet Peninsula (after Forsyth et al. *1995 as modified to 17/8/2001; original sources include Cocker 1977, Bacon & Corbett 1984, Dunderdale 1989 and K. D. Corbett, pers. comm.).*

ellipsoidal in shape and very variable in size, with long dimensions ranging from a few tens of millimetres to commonly 0.4 m or more. A few are crudely polygonal or irregular in shape (pl. 3), but with generally rounded rather than angular corners. Contacts against the host adamellite are usually quite sharp, but without fine-grained margins, and slightly wavy on a very small scale. Some of the smaller enclaves are coarser-grained, paler (with less biotite) and less mafic. These generally also have more diffuse margins and are texturally transitional to the host adamellite. Many enclaves contain scattered microphenocrysts, oblong to equant polygonal in outline, of dull white feldspar.

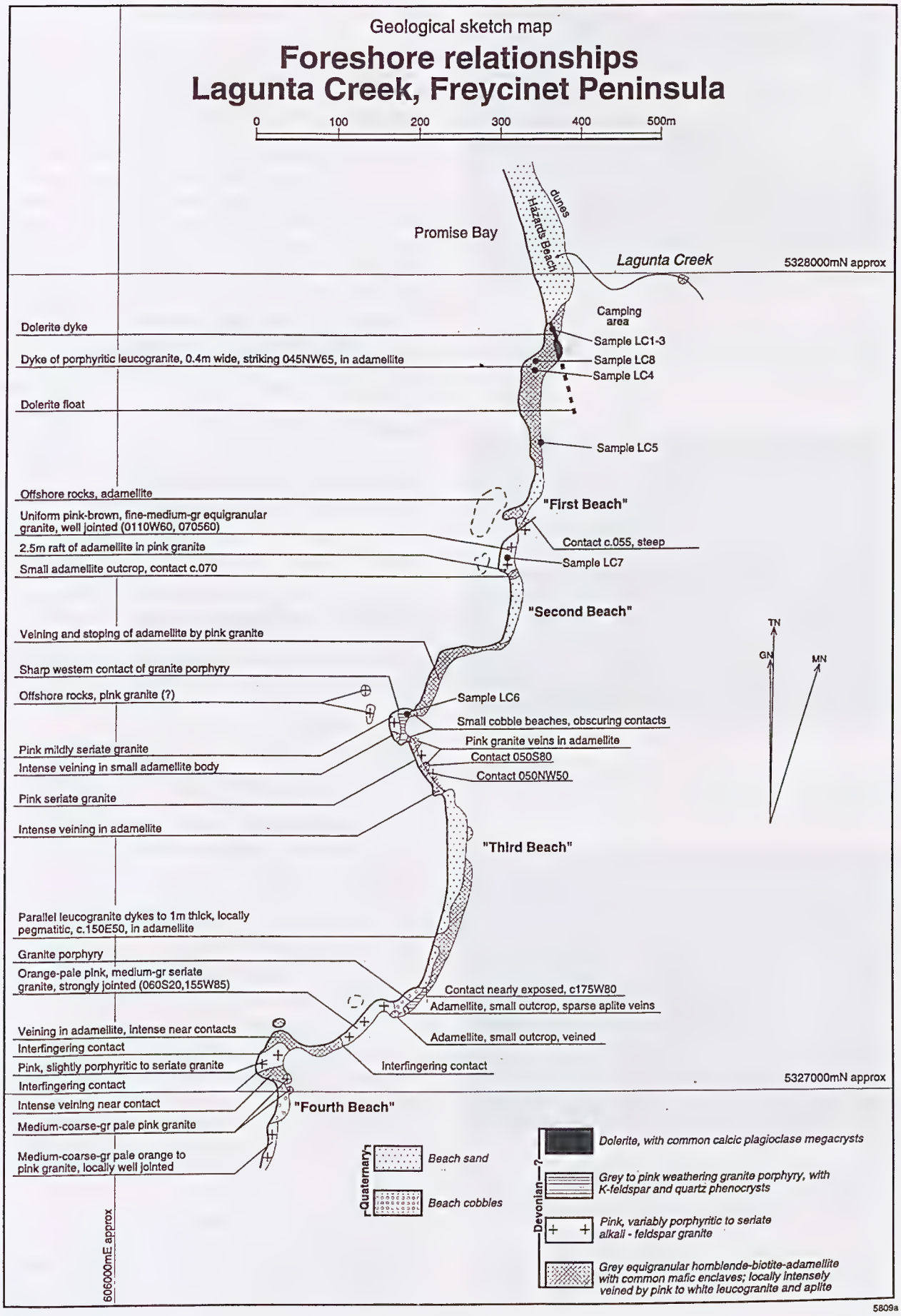

FIG. 2 — Geological sketch map, foreshore relationships south of Lagunta Creek, Freycinet Peninsula.

PLATE 1
General view looking north from near the mouth of Lagunta Creek at the southern end of Hazards Beach, showing in foreground the stepped western contact of the dolerite dyke with adamellite.

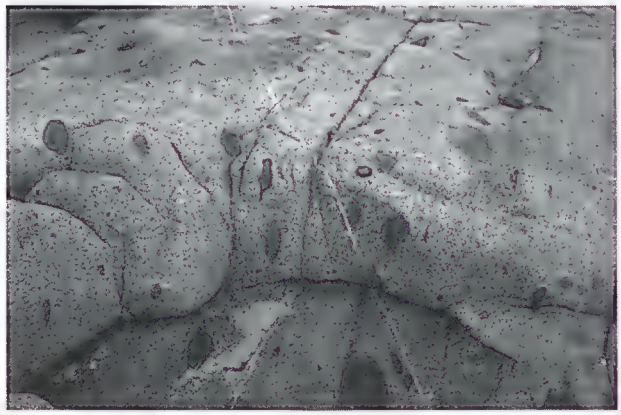

PLATE 2
General view of adamellite, showing numerous, mostly ellipsoidal to irregular enclaves and narrow aplite vein. The diameter of the lens cap is 50mm.

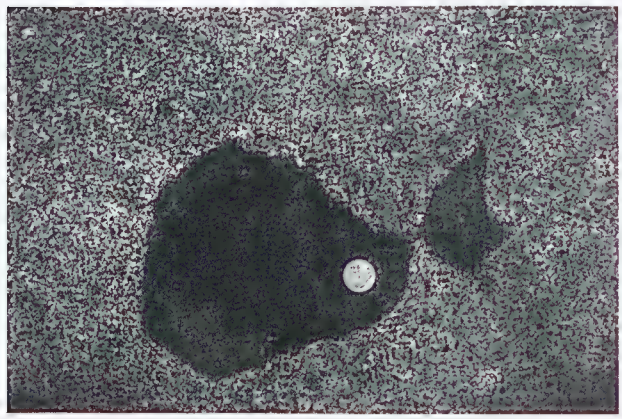

PLATE 3
Close-up of enclaves within adamellite. The larger enclave is atypical in its crudely polygonal shape. The diameter of the coin is 28 mm.

Petrography

In thin section the adamellite (sample LC4) is seen to consist mainly of quartz, feldspar (plagioclase more abundant than alkali feldspar), biotite and hornblende. Zircon, titanite, allanite, apatite, opaque minerals and chlorite (as an alteration of biotite) are accessory minerals.

Quartz occurs as clear unstrained anhedra, mostly 1–3 mm across. Plagioclase is typically oblong subhedral (up to 2 mm long) and in places shows incipient sericitisation. Extinction angles show that it may be as calcic as An_{48}, but concentric zoning is frequently apparent. Potash feldspar (orthoclase) is typically equidimensional and subhedral, and also often strongly and concentrically to irregularly zoned, and partly sericitised. Biotite is pleochroic from very dark brown to pale yellow-brown and is locally partly altered to pale green chlorite. Hornblende (pleochroic with α pale yellow-brown, β olive-green, χ sea-green) occurs as elongate bladed prisms up to 1.5 mm long and irregular clots up to 2 mm across, which may enclose cores of sieve-textured relict clinopyroxene. Hornblende and biotite are often closely associated and sometimes intergrown. Both minerals occasionally occur as inclusions in quartz, indicating that they crystallised earlier.

Allanite occurs as scattered, rather turbid, isolated equant euhedra, in section polygonal and up to 0.8 mm across. Typically it is pale orange-brown, weakly pleochroic and only partly metamict but variably altered to paler to colourless secondary minerals. Radiating cracks in enclosing quartz and feldspars, and bent adjacent biotites, are attributed to strain caused by increase in volume during metamictisation. Occasional zircon grains, small apatite rods and rare tiny opaque blebs occur mainly as inclusions in biotite and hornblende. These accessory minerals are considered to be early crystallising, or possibly restite, phases. In contrast, titanite occurs as fine-grained anhedral aggregates and is probably secondary.

The hornblende adamellite (sample LC4) is essentially non-magnetic (susceptibility 0.1–0.2 x 10^{-3} SI), and it is a reduced or ilmenite-series granite (Ishihara 1977).

A thin section of a mafic enclave (sample LC5A) shows that it is mineralogically similar to the host adamellite, but is finer-grained (mostly less than 0.5 mm), and mafic minerals are more abundant. Hornblende (pleochroic from sea-green to pale yellow-green) occurs with minor biotite (dark brown to pale yellow) in clots several millimetres across. Quartz, plagioclase and orthoclase, together with accessory zircon and apatite, are also present. Opaque phases are very sparse.

Petrographically very similar enclave-bearing equigranular hornblende-biotite adamellite/granodiorites occur at the northern end of Wineglass Bay (sample WGB, AMG reference FP07203115) and near Cape Tourville (sample CTV, FP09503530). The former is slightly more felsic than sample LC4 and apparently lacks relict clinopyroxene, whilst the latter has more extensively altered feldspar.

Geochemistry

A major element analysis (table 1) of adamellite (sample LC4) shows a relatively mafic (<70%), strongly metaluminous (ASI<1) composition. Calculated pseudomodes suggest that the rock is an adamellite in the modified Streckeisen (1973) classification scheme (fig. 3). Similar rocks from

Wineglass Bay (sample WGB; sample CD8 of Dunderdale 1989) and the Cape Tourville–Sleepy Bay area (sample CTV; samples TB6 and TB54 from database of B.W. Chappell) plot as slightly more quartz-rich adamellites, transitional to granodiorite.

In detail, sample LC4 is slightly more mafic than the Wineglass Bay and Cape Tourville rocks, with generally lower SiO_2 and higher TiO_2, total FeO, MgO and CaO. On simple two element variation diagrams (e.g. figs 4A–D) the available analyses generally plot colinearly, suggesting derivation from a common source, followed by differentiation by variable degrees of separation of entrained restite from the melt (e.g. Chappell & White 1992). It is proposed that these adamellite/granodiorites be termed the Bluestone Bay Suite.

Petrographically and chemically these rocks are clearly I-type granites. The low SiO_2, Rb (< 250 ppm) and high Sr (>50 ppm) and Ba (>200 ppm) identify them as unfractionated granites, using the criteria of Chappell *et al.* (1991).

For most elements, the enclave LC5 generally lies near extrapolations of the trends defined by the host granites to more mafic compositions, and on this basis it could represent an aggregate of modified restite (following White & Chappell 1977, Chen *et al.* 1989). However, other interpretations are possible. Similar mafic enclaves are found within other relatively mafic granites in eastern Tasmania, eastern Australia and worldwide. Most workers have interpreted them as globules of basaltic magma that were injected into the partly molten granite and incompletely mixed (mingled) with it (e.g. Reid *et al.* 1983, Vernon 1984), but others regard them as cumulates genetically related to the granite (e.g. Flood & Shaw 1995).

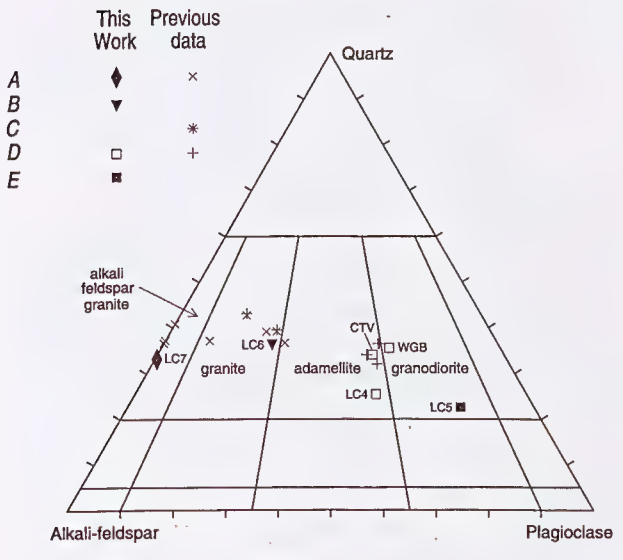

FIG. 3 — Calculated pseudomodes of analysed granitic rocks from Freycinet Peninsula, plotted on the granitoid classification diagram of Streckeisen (1973), modified by the separation of an adamellite (= monzogranite or quartz monzonite of some authors) field from the granite field. (A) Pink alkali feldspar granite and related rocks; (B) granite porphyry; (C) white granite at Fleurieu Point; (D) grey adamellite; (E) enclave in grey adamellite.

Comparison with Other Eastern Tasmanian Granites

The nearest outcropping adamellite/granodiorites are small coastal exposures on Long Point and Piccaninny Point, some 40–50 km to the north. These are apparently similar coarse, even-grained to slightly porphyritic, medium-grained, enclave-bearing hornblende-biotite granites (Turner & Calver 1987: 63–64). However, compared to the Bluestone Bay Suite, the two available analyses (Turner *et al.* 1986) have distinctly higher MgO (fig. 4A) and lower Na_2O, Al_2O_3, Sr (fig. 4C) and Th at equivalent total FeO.

As noted by Turner *et al.* (1986), the St Marys Porphyry (the partly extrusive equivalent of an I-type granodiorite) and other members of the Scamander Tier Suite are chemically dissimilar to the Long Point/ Piccaninny Point adamellite/granodiorites. The Scamander Tier suite rocks also differ from the Bluestone Bay Suite, with higher SiO_2, Y (fig. 4D) and Zr and lower Al_2O_3, MgO (fig. 4A), CaO (fig. 4B), Na_2O, Sr (fig. 4C) and Th at equivalent total FeO.

In addition, both the 388 ± 1 Ma Rb/Sr emplacement age of the St Marys Porphyry and the similar ages (385–389 Ma) of the Piccaninny Point adamellite (Turner *et al.* 1986) are much older than 372.8 ± 3 Ma Rb/Sr age of Cocker (1977) from north of Sleepy Bay.

The small Piccaninny Creek pluton (Turner *et al.* 1986) near Chain of Lagoons (not to be confused with the body at Piccaninny Point) is also chemically unlike the Bluestone Bay Suite (figs 4A–D).

Further north, the hornblende-bearing granodiorites of the Blue Tier Batholith are unlikely correlates, as there is unequivocal field and isotopic evidence that at least the Gardens and George River granodiorites are still older than the rocks of the Scamander Tier Suite (e.g. McClenaghan *et al.* 1992).

PINK ALKALI FELDSPAR GRANITE

About 300 m south of Lagunta Creek, a few metres to the south of a small sandy beach, a small exposure of enclave-bearing adamellite has a probably steep and northeasterly trending contact (not quite exposed) against a much more felsic, pink to red, medium- to fine-grained, equigranular granite. The pink granite is well jointed, very uniform, and lacks aplite veins or enclaves.

About 75 m further south, at the northern end of a second small sandy beach, there is a contact, striking at about 250°, against a small (3 x 3 m) flat outcrop of white enclave-bearing adamellite to the south. Here the pink granite is equigranular to variably porphyritic, locally containing small phenocrysts of potassium feldspar (5–15 mm) and quartz (≤ 5 mm). Narrow, finer grained leucogranite and aplite dykes occur within it, but unlike those in the adamellite which they otherwise resemble, their margins and terminations are frequently diffuse and indistinct. They appear to be late stage segregations directly derived from the pink granite.

South of the second sandy beach, the enclave-bearing adamellite is intruded by dykes, up to 80 mm wide, of medium-grained equigranular pink granite. The dykes become wider (up to 1 m) and more numerous southward, and form a network throughout the adamellite (pl. 4). Locally they are very coarse-grained to pegmatitic (20–

TABLE 1
New chemical analyses of Devonian granites and dolerite, Freycinet Peninsula

Field no.	LC4	LC5	WGB	CTV	LC7	LC6	LC1	LC3
Reg. no.	004439	004440	004450	004451	004443	004442	004436	004438
Analysis no.	910750	910751	980424	980423	910753	910752	910748	910749
AMG (FP...)	06512788	06522780	07203115	09503530	06482765	06362746	06532793	06532793
Rock type	adamellite	enclave	adamellite	adamellite	granite	porphyry	chilled dol	dolerite
SiO2 (wt%)	65.63	61.30	67.90	68.45	75.71	73.04	45.52	44.58
TiO2	0.60	0.79	0.57	0.48	0.09	0.20	2.89	2.61
Al2O3	15.14	15.44	14.54	14.73	12.46	12.24	14.99	15.25
Fe2O3	0.88	1.26	0.68	0.53	0.94	0.57	2.39	3.12
FeO	3.22	4.80	3.16	2.78	0.46	1.32	10.13	8.88
MnO	0.08	0.13	0.07	0.07	0.01	0.03	0.21	0.20
MgO	2.46	4.01	2.04	1.71	0.06	0.20	7.05	7.25
CaO	4.55	5.99	4.11	3.73	0.64	0.78	8.59	8.25
Na2O	3.54	3.68	2.89	2.96	3.19	2.90	3.79	3.60
K2O	3.24	1.80	3.06	3.54	5.92	5.17	1.24	0.98
P2O5	0.17	0.19	0.13	0.12	0.00	0.04	0.86	0.76
H2O+	0.87	1.11	0.72	0.80	0.19	0.79	3.31	3.37
CO2	0.11	0.04	0.13	0.08	0.09	0.07	0.07	0.06
SO3	0.04	0.03	0.04	0.03	0.03	0.03	0.03	0.04
FeS2	0.00	0.00	nd	nd	0.00	0.00	0.01	0.00
TOTAL	100.53	100.57	100.04	100.01	99.79	97.38	101.08	98.95
Sc (ppm)	<9	11	14	11	<9	<9	20	14
V	90	115	80	65	8	18	290	250
Co	8	14	12	10	<8	<8	50	58
Ni	17	29	19	16	8	7	56	64
Cu	16	11	12	7	13	13	30	25
Zn	44	64	62	67	20	30	103	92
Ga	15	17	18	18	21	18	19	21
As	<20	<20	<20	<20	<20	<20	<20	<20
Rb	142	138	145	170	320	333	76	64
Sr	346	266	320	340	31	60	366	411
Y	20	30	25	22	60	57	47	40
Zr	130	136	155	145	133	149	354	313
Nb	3	6	10	9	11	8	11	9
Mo	<5	<5	<5	6	<5	<5	<5	<5
Sn	<9	<9	<9	<9	9	<9	<9	<9
Ba	600	230	500	520	220	270	310	330
La	42	<20	44	35	72	52	<20	<20
Ce	81	36	88	61	140	100	85	67
Nd	44	43	32	21	98	68	64	60
W	<10	<10	<10	<10	<10	<10	11	11
Pb	20	<10	18	21	44	25	<10	<10
Bi	6	6	<5	<5	5	<5	8	7
Th	26	<10	31	21	43	39	<10	<10
U	15	<10	<10	<10	14	20	<10	<10
FeOt*	4.01	5.93	3.77	3.26	1.31	1.83	12.28	11.69
ASI	0.860	0.817	0.936	0.951	0.972	1.039	0.646	0.694
K/Rb	189.4	108.3	175.2	172.9	153.6	128.9	135.4	127.1

* FeOt is total iron expressed as FeO. ASI is alumina saturation index (molar Al2O3/(CaO+Na2O+K2O).

50 mm), with needles (≤ 30 mm long) and angular clots of black tourmaline. Dyke margins are sharp, usually fairly straight, and intersect with sharp corners. In places, irregularities in opposite dyke walls can be matched (pl. 5). Locally the proportions of pink granite dykes and adamellite country rock are about equal, with the latter partly occurring as angular stoped blocks, from a few tens of millimetres to metres across, in the pink granite. These features indicate dilational emplacement, and suggest that the adamellite was solid and capable of brittle fracture at the time of emplacement of the pink granite dykes.

The tip of a small headland about 600 m south of Lagunta Creek is composed of pinkish, slightly porphyritic to seriate granite with minor biotite. Pink feldspar phenocrysts (5–30 mm) and equant quartz phenocrysts (≤5 mm) both grade into the relatively coarse (1–3 mm) groundmass. This rock type appears to be a textural variant of the equigranular pink granite further north. To the

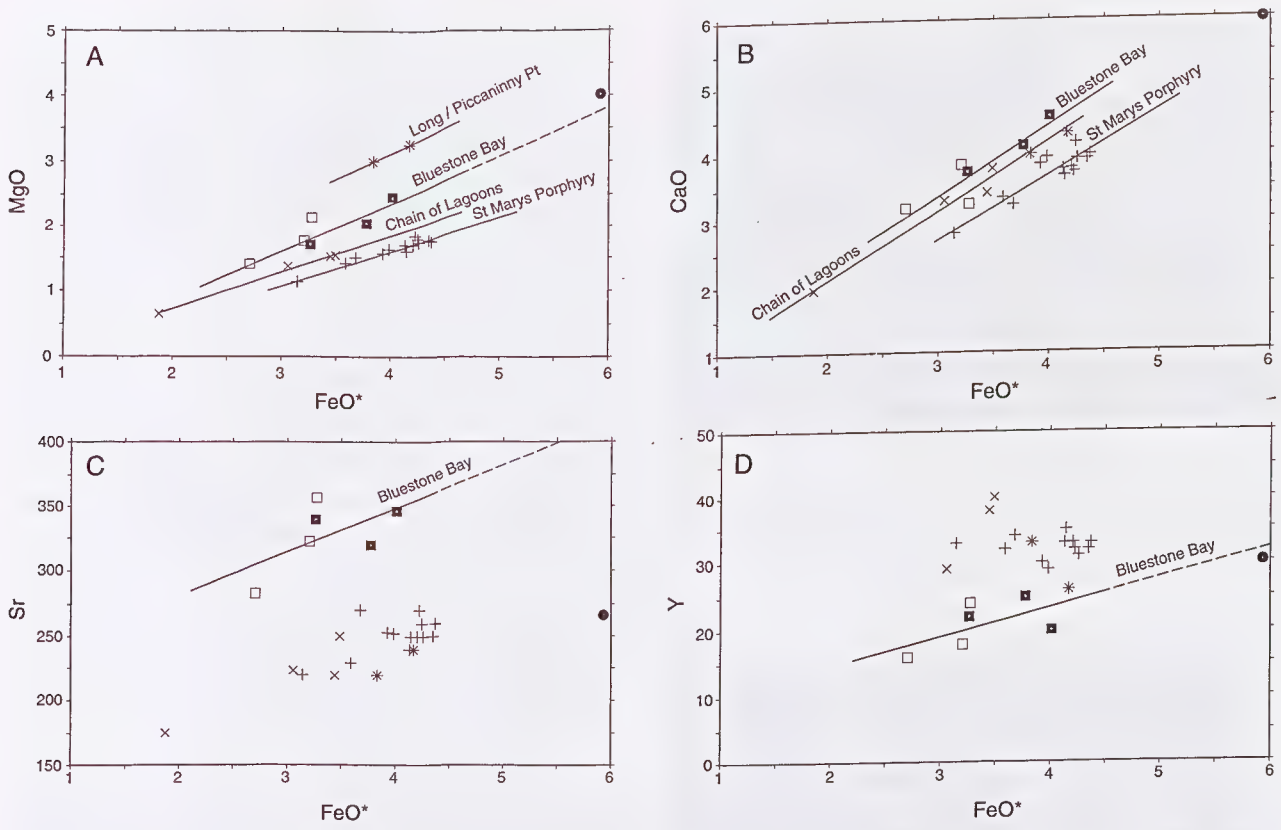

FIG. 4 — Selected two element variation diagrams for hornblende-bearing adamellite/granodiorites from central eastern Tasmania: Bluestone Bay Suite (■ – this paper, □ – previous data), enclave LC5 (⊙), Long Point and Piccaninny Point (✳), Chain of Lagoons (Piccaninny Creek)(×) and St Marys Porphyry (+). Regression lines, where well-defined, are also shown. See text for further discussion and data sources. (A) MgO against total iron. (B) CaO against total iron. (C) Sr against total iron. (D) Y against total iron.

south of the headland, which is transected by a dyke-like body of distinctive granite porphyry (see below), there is an irregular contact against enclave-bearing adamellite which contains abundant dykes of pink granite and related pegmatitic and leucogranitic veins. A complex area of intensely veined adamellite and one or more small intrusions of similar pink seriate granite extends southward for 80 m to the northern end of the third sandy beach.

More outcrops of similar pink to brown, porphyritic to seriate, usually well-jointed felsic granite intrude adamellite near a headland 1 km from Lagunta Creek. Contacts are usually interfingering, with dykes and veins of pink leucocratic granite extending into and throughout the adamellite exposures.

Further south, adamellite is absent, and almost continuous coastal exposures of pink granite and its textural variants extend to Cooks Beach.

Petrography

A sample (LC7) from about 350 m south of Lagunta Creek consists of an allotriomorphic intergrowth of mainly anhedral quartz (1–3 mm), anhedral, turbid perthitic feldspar and anhedral to subhedral, turbid, weakly zoned plagioclase (probably largely albite). Mafic minerals are sparse (<1 %) and mainly comprise ragged flakes (≤ 2.5 mm) of biotite (a pale yellowish brown, b and c dark brown to nearly opaque) partly altered to chlorite, but there is also minor interstitial biotite with different pleochroism (a pale brownish yellow, b and c dark green). Accessory minerals include zircon and rounded to nearly square opaque grains (0.15–0.8 mm), which are larger and more abundant than in the adamellite. Slightly elongate euhedra (<0.4 mm) of an orange-brown material may be altered allanite.

Sample LC7 has a high magnetic susceptibility of about 5×10^{-3} SI, suggesting that the opaque mineral is magnetite. This may be a local characteristic, as apparently similar pink to red granite outcrops at Coles Bay township, Cape Tourville lighthouse, the eastern headland of Bluestone Bay, and the southern end of Friendly Beaches gave very much lower values (< 0.1×10^{-3} SI).

Geochemistry

The rock (LC7) has a highly felsic, mildly metaluminous composition. Its pseudomode plots as alkali feldspar granite (fig. 3), since plagioclase is essentially albite. High Rb (>250 ppm) and low Sr (<50 ppm) identify it as a fractionated granite, although Ba is a little higher than the suggested 200 ppm limit. In addition to the metaluminous character, its negligible P_2O_5 and relatively high rare earth elements (REE), Th, Y and Pb are characteristic of fractionated I-types (Chappell & White 1992). This is due to the low solubility of apatite in metaluminous melts, which results in the early removal of P_2O_5 from the liquid; thus monazite does not crystallise and REE and Th are concentrated in the liquid (e.g. Sawka *et al.* 1990). In felsic I-type granites, REE mostly occur in allanite (e.g. Bea 1996).

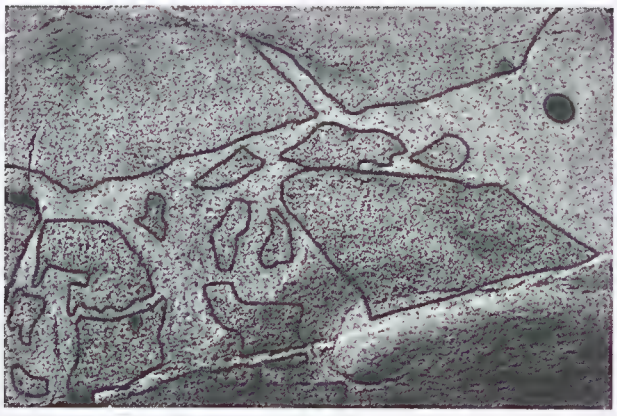

PLATE 4
Dilational intrusion of pink alkali feldspar granite, stoping blocks of grey adamellite, about 500m south of Lagunta Creek. The contacts have been outlined for clarity. The diameter of the lens cap is 50mm.

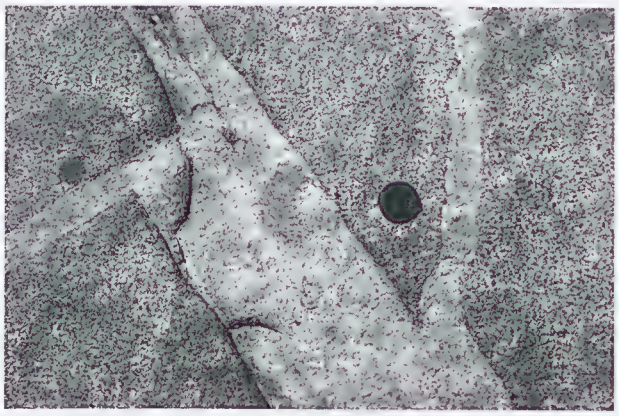

PLATE 5
Close-up showing dilational intrusion of pink alkali feldspar granite into grey adamellite. Lens cap 50 mm diameter.

PLATE 6
Irregular contact of dolerite dyke, cross-cutting earlier veins of aplite veins within adamellite, near mouth of Lagunta Creek.

Comparison with Other Eastern Tasmanian Granites

More extensive sampling (data of B. W. Chappell and others, available in MRT "ROCKCHEM" database) shows that similar felsic fractionated I-type granite is widespread on Freycinet Peninsula and extends to the eastern part of Schouten Island. It is proposed to assign these granites to the Freycinet Suite.

The only other felsic fractionated I-type granites in the region are from the southern part of the Ben Lomond granite (Chappell & White 1992; J.L. Everard, pers. obs.) and the Mt Stronach alkali feldspar granite of the Scottsdale Batholith (Robinson 1982, McClenaghan *et al.* 1982). The Ben Lomond granite in particular shows some similarities to the Freycinet Suite, such as high Y, Ce and Th and low ASI and P_2O_5, but its spatial separation and slightly younger Rb/Sr age (c. 362 Ma adjusted for new decay constants, McDougall & Leggo 1965) probably preclude a direct correlation. Granites of the Ile des Phoques, Maria Island and Deep Glen Bay (Clarke & Baillie 1984, M.P. McClenaghan and J.L. Everard, pers. obs.) are, in contrast, felsic fractionated S-types.

LEUCOGRANITE AND APLITE DYKES

Dykes of off-white to very pale grey, aphanitic aplite are fairly common within the adamellite at Lagunta Creek. They are variable in width (typically 15–80 mm) and locally pinch out. They have sharp contacts and locally truncate or dilationally transect the mafic enclaves, but terminate against the dolerite dyke (pl. 6). This establishes an order of intrusion, and also indicates that the enclaves are older than, and not directly related to, the dolerite dyke. In one place a small fault, with a throw of about 45 mm, offsets an aplite dyke.

On a small headland about 150 m south of Lagunta Creek, adamellite is cut by a 350–400 mm wide dyke of off-white to pale-grey, pale-pink to red weathering, porphyritic leucogranite. Small oblong phenocrysts of dull white (potassium?) feldspar (5–20 mm) and smaller (≤ 5 mm) equant quartz phenocrysts are somewhat sparsely scattered in a fine-grained leucocratic groundmass containing very little biotite. Contacts with the surrounding adamellite are sharp and slightly wavy to curved, and truncate enclaves within it. Thin irregular to curved aplite veins (a few millimetres to 10 mm wide) shoot off the leucogranite dyke for several metres into the adamellite, in places transecting enclaves without lateral displacement.

Further south, similar leucogranite and aplite can be seen to originate in the pink granite and occur as dykes and diffuse segregations within it. Thus, they belong to the same intrusive phase, which is younger than the adamellite.

Petrography

In thin section, a sample (LC8) of porphyritic leucogranite resembles the main pink granite. Phenocrysts of quartz are set in an allotriomorphic quartz-perthite intergrowth containing rare biotite (pleochroic from very dark brown to almost colourless) and substantial amounts of opaque accessory minerals (probably magnetite). Also like the pink granite, the hand specimen has a high magnetic susceptibility (about 4×10^{-3} SI).

GRANITE PORPHYRY

This rock type occurs at two localities. The northernmost occurrence is about 600 m south of Lagunta Creek, where a north–south trending body, possibly a dyke about 15 m wide, is exposed over a strike distance of about 35 m on a small headland.

The rock is a dark-grey, reddish-brown to pink weathering, visually striking porphyritic granite, containing very abundant phenocrysts of feldspar (10–40 mm long) and globular quartz (≤ 5 mm), together with small clots of biotite (to 3 mm) in a grey fine-grained leucocratic groundmass. There is a preferred direction of alignment of the feldspar phenocrysts at an azimuth of about 10°, approximately parallel to the strike of the body. No enclaves, dykes or veins are present.

Enclave-bearing adamellite, veined by pink leucogranite, lies on the eastern side of the porphyry, but the contact is obscured beneath beach boulders (of mainly granite porphyry) on the shore, and soil behind the headland. At the northern end of the "dyke", the western contact with a pinkish, less porphyritic to seriate granite trends at about 170° to 190° but is locally slightly wavy to irregular. About 25 m to the south, on the south side of the headland and west of the porphyry, a small (less than 10 x 10 m) body of grey enclave-bearing adamellite is intensely veined by pink leucocratic granite offshoots of the seriate granite to the north. Thus, the porphyry may be later than, although possibly related to, the pink seriate granite.

Similar granite porphyry occurs 800–900 m south of Lagunta Creek at the southern end of the third sandy beach. Here grey adamellite occurs behind the beach to the northeast; the contact probably strikes at about 170° and is subvertical or dips very steeply to the west. The porphyry has a grey chilled margin 20–50 mm wide, against (to the east) a pink microgranite about 100 mm wide; sand obscures the actual contact with adamellite 1.5 m further east. These relationships are consistent with the porphyry being younger than the adamellite. About 40 m southwest of this locality, the porphyry body passes southward to a small, poorly exposed outcrop of adamellite. Here the contact is obscured, but possibly strikes at about 135°.

Petrography

In a thin section of granite porphyry (sample LC6), the quartz phenocrysts are clear, rounded euhedra and slightly embayed subhedra, whilst both potassium feldspar and sodic plagioclase phenocrysts are turbid and euhedral. The latter contain numerous small inclusions of secondary white mica. Biotite (α pale brownish yellow, β and χ dark green) occurs as small euhedral to ragged phenocrysts, irregular clots and as inclusions in quartz and feldspar phenocrysts. It is, therefore, an early crystallising mineral, although now partly altered to chlorite and muscovite. Zircon, monazite and opaque grains are abundant as inclusions within biotite. The groundmass consists of fine-grained (0.02–0.05 mm) quartz and feldspar, with subordinate splinters of partly altered biotite.

The hand specimen is essentially non-magnetic (susceptibility about 0.1 x 10^{-3} SI).

Geochemistry

The granite porphyry is not quite as felsic as the pink granite LC7 (lower SiO_2, higher total FeO, TiO_2, MgO and CaO), and the pseudomode plots as granite (*sensu stricto*) (fig. 3). Although Rb is slightly higher, so are Sr and Ba, and the rock is probably less fractionated. This is consistent with lower to slightly lower REE, Y, Th and Pb, and higher (but still very low) P_2O_5. Although weakly peraluminous, there is little doubt that this rock is also an I-type.

DOLERITE DYKE

Near the mouth of Lagunta Creek, a conspicuous black dolerite dyke intrudes the grey adamellite (pl. 1). At its northern end, where it disappears beneath sand at the southern end of Hazards Beach, it is about 6.5 m wide. It can be followed southward (trending at about 165°) diagonally across the shore platform for about 70 m until it disappears due to poor inland exposure.

Dyke margins are chilled for about 50 mm from the contacts, but the adjacent adamellite is uniform in appearance right up to the contact and appears unaffected by the dolerite. The central part of the dyke has a grain size of typically 0.5–1 mm but is locally coarser-grained and very feldspathic, with plagioclase laths 1–3 mm long grading up to a few microphenocrysts 5–10 mm long and larger, in a sea-green weathering mesostasis. Sporadic (< 1% by volume) but large and conspicuous plagioclase megacrysts (pl. 7), typically measuring 10–30 x 5–20 mm but up to 140 x 50 mm, are more common in the northern part of the dyke, and in its centre rather than near its margins. They are mostly oblong to rhomboid euhedra and subhedra with rounded corners, and are off-white to pale pink, sometimes with clear cores, or clear throughout.

The eastern (landward) contact of the dyke is sharp and exposed continuously for 9 m, and intermittently for a further 18 m. It strikes at 165° and dips at 75° to 85° to the east but is locally irregular. At some irregularities, fingers and offshoots of dolerite (one 130 mm long) extend into the adamellite.

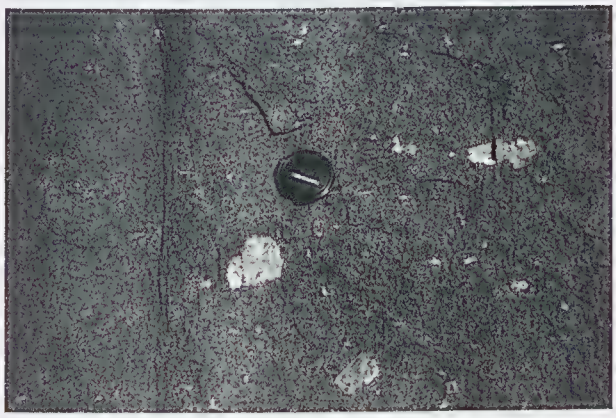

PLATE 7
Close up of dolerite dyke showing plagioclase megacrysts. Lens cap 50 mm diameter.

The western (seaward) contact is better exposed, nearly completely so for the most northern 35 m of the dyke. It has a similar overall trend and steep generally eastward dip but is more irregular than the eastern contact. Although always sharp, the contact varies from locally straight (on a scale of a few millimetres) for up to a metre or more with abrupt changes in direction, to elsewhere highly irregular. In several places, it is clearly controlled by jointing within the host adamellite.

At several places near the western contact, irregularly shaped, angular-stoped blocks of adamellite up to 0.5 m long occur within the dolerite. In some cases, their shape can clearly be matched with irregularities in the adjacent wall of the dyke, indicating dilational emplacement.

Both contacts, but especially the western one, show a tendency to step abruptly eastward as one follows them to the north (i.e. dextrally). At each of two such places near the northern end of the western contact, a finger of dolerite, initially about 0.5 m wide, shoots off northward for several metres into the adamellite (pl. 8). The two fingers are subparallel and linked by narrow cross-dykes. Each finger gradually narrows northward and tapers away, but the trends continue as joints within the adamellite. About 7 m west of the main dyke, another narrow (70–150 mm wide) dyke occurs within the adamellite. Its strike is irregular, and to the south it trends at about 150° towards the main dyke, which it probably joins beneath soil cover.

In several places, the contacts of the dolerite dyke abruptly crosscut mafic enclaves within the host adamellite. Aplite and leucogranite veins are also abruptly truncated against the contact (pl. 6), and nowhere are found within the dolerite, indicating that the latter is younger.

The sharp angular contacts of the dyke, their control by jointing in the host, the chilled margins and the stoped blocks suggest that the adamellite had already essentially cooled and solidified at the time of dyke emplacement.

Petrography

A sample (LC3) from the centre of the dyke consists of a subophitic intergrowth of weakly zoned, pinkish titanaugite granules (≤ 1 mm), turbid plagioclase and ragged opaques (magnetite?), together with scattered equant pseudomorphs of former olivine (≤ 0.8 mm across), now replaced by fine-grained, colourless and nearly isotropic serpentine and magnetite dust. Secondary chlorite, epidote and actinolite are also present. Some large (1 mm) crystals of a mineral (probably titanite) with very high relief and birefringence are later than plagioclase. The plagioclase megacrysts are difficult to extract, but a chip gave an electron microprobe analysis of $An_{64.5}Ab_{34.1}Or_{1.4}$ (calcic labradorite).

The chilled margin (sample LC1) is mineralogically similar. Laths of plagioclase (≤ 0.3 mm long) grade down to an intergranular groundmass of plagioclase, titanaugite granules and generally elongate opaques (≤ 0.05 mm long), together with secondary chlorite and actinolite. Minute fragments of a brown pleochroic mineral (probably biotite) are closely associated with chlorite. Abundant amygdales (≤ 0.5 mm) are filled with strongly pleochroic (yellow to green) chlorite with anomalous blue to purple birefringence.

These samples have a high magnetic susceptibility (23–25 x 10^{-3} SI), consistent with the presence of abundant magnetite.

PLATE 8
Offshoot of dolerite dyke from western contact, intruding along joints in adamellite, near mouth of Lagunta Creek. The hammer is 400 mm long.

Geochemistry

There is little difference between analyses (table 1) of the chilled margin (LC1) and the central part of the dyke (LC3). The dolerite has an alkalic major element chemistry, and is normatively a hawaiite (ne < 5%; plagioclase normatively andesine). Low MgO, Mg# (54.7 and 56.7 at Fe_2O_3/FeO = 0.20) and Ni indicate that the dolerite is not an unmodified partial melt of primitive mantle, but has undergone olivine ± pyroxene fractionation. Other notable features of the major element chemistry are rather high Al_2O_3 (consistent with the presence of probably cognate plagioclase megacrysts, the likely crustal liquidus phase) and rather high TiO_2.

The main features of the incompatible trace element geochemistry are very low Nb (especially for an undersaturated rock with alkalic major element chemistry), low Sr, high Y and low K/Rb. This is clearly seen in a primitive mantle normalised spider diagram of available trace elements (fig. 5), which displays negative Nb and Sr anomalies relative to adjacent elements of similar incompatibility. Whilst low Sr may simply reflect fractionation of plagioclase, Nb is unlikely to have been depleted by either fractionation or alteration. By comparison, the average chilled margin of Tasmanian Jurassic dolerite (Hergt *et al.* 1989) is much lower in TiO_2, P_2O_5, Zr and Nd, whilst Triassic hawaiite from near St Marys (Everard 1987) lacks a negative Nb anomaly.

The dolerite dyke may be part of a large swarm that is widespread in northeast Tasmania, but best developed in the Blue Tier–Great Musselroe River area (e.g. McClenaghan & Williams 1983). However, similar dolerite dykes occur from south Maria Island (microdiorite of Clarke & Baillie 1984) to at least the northern tip of Flinders Island (J.L. Everard, pers. obs.). Their geochemistry (e.g. McClenaghan *et al.* 1982, 1992, McClenaghan 1984, Baillie 1986, MRT ROCKCHEM database) is highly variable, ranging from basaltic to andesitic (SiO_2 46–60%) and from tholeiitic and weakly alkaline. They pre-date the Late Carboniferous to Middle Triassic Parmeener Super-group but intrude both the Ordovician-Early Devonian Mathinna Group and the Middle-Late Devonian granites. However, one tholeiitic dyke at Lady Barron, Flinders Island is transected by quartz feldspar porphyry, suggesting at least locally a syn-granitic Devonian age (Baillie 1986: 29).

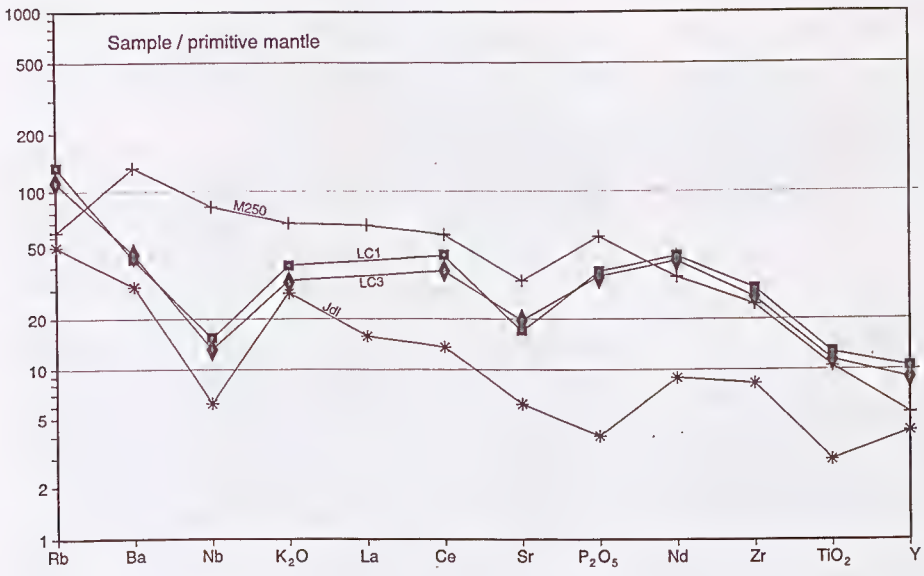

FIG. 5 — Primitive mantle normalised incompatible element spider diagram (after Sun & McDonough 1989), for dolerite dyke at Lagunta Creek (samples LC1, LC3). Average chilled margin of Tasmanian Jurassic dolerite (Hergt et al. *1989) and Triassic basalt (M250) at St Marys (Everard 1987) also plotted for comparison.*

The Lagunta Creek dyke, which is younger than one of the youngest eastern Tasmanian granites (c. 373 Ma), is the one of the most mafic (the lowest SiO_2) and most alkaline (high Na_2O+K_2O) representatives yet analysed. Trace element data for other dykes are limited (especially for rare earth elements) but two dykes from the Pyengana area also display negative Nb anomalies (relative to K, Ba and Ce) on mantle-normalised spider diagrams (J.L. Everard, pers. obs.).

Soesoo & Nicholls (1999) have reported similar negative Nb anomalies from certain mafic rocks associated with Devonian Lachlan Fold Belt granites in eastern Victoria, and suggested, by analogy with modern volcanic rocks, a subduction-related, island arc or continental margin tectonic setting for them. Alternatively, it could be a crustal signature, indicating either a component derived by direct melting of continental crust (cf. Morris *et al.* 2000), or indirect contamination of the mantle source by subducted pelagic sediments (cf. Hergt *et al.* 1989).

DISCUSSION AND CONCLUSIONS

The similarity of the grey enclave-bearing hornblende adamellite at Lagunta Creek to the body exposed 3 km to the north at Wineglass Bay suggests that they are part of the same pluton. More adamellite occurs 5 km to the northwest, between Sleepy Bay and Bluestone Bay (fig. 1). These adamellites appear to belong to the distinctive Bluestone Bay Suite and, although the oldest granites in the district, are dissimilar to and younger than other I-type granodiorite/adamellite intrusions of the Blue Tier Batholith.

A contact, accompanied by numerous quartz veins, with an altered pink granite is exposed on the headland (FP105345) between Sleepy Bay and Carp Bay. At Bluestone Bay, the eastern headland comprises pink fine-grained to pegmatitic felsic granite, whereas to the northwest there is more enclave-bearing grey adamellite/granodiorite. At each of these localities, as at Coles Bay (Groves 1965) and Lagunta Creek, the adamellites are intruded by pink granite, or by aplite and leucogranite dykes related to it. This uniform order of intrusion throughout the district is consistent with the Rb/Sr isotopic ages. The now disjunct bodies of hornblende adamellite are probably eroded remnants of a roof pendant that was intruded from below by younger pink granite, a felsic fractionated I-type. The coastal section south of Lagunta Creek, in particular, appears to represent a thin roof pendant of adamellite, intensely intruded and stoped by the pink granite. Some of the smaller adamellite bodies may be disconnected rafts.

Chappell *et al.* (1991) listed the Coles Bay, Hazards, Freycinet (south of the Hazards isthmus) and Schouten granites as separate felsic I-type plutons, whilst a small body at Bluestone Bay was considered to be an unfractionated mafic I-type. However, all the felsic bodies (Freycinet Suite) are chemically similar, although the Hazards body is the most fractionated (Chappell & White 1992). Furthermore, granite bedrock is probably continuous below sea level beneath both the Hazards isthmus and Schouten Passage. Concealed screens of country rock are unlikely to be present, as elsewhere in eastern Tasmania hornfelsed Mathinna Group is commonly a resistant, topographically prominent lithology.

The later dolerite dyke at Lagunta Creek is a fractionated hawaiite with an unusual crustal and/or subduction-related trace element signature. Further work on other granite-associated mafic rocks in eastern Tasmania and elsewhere is necessary to evaluate its significance. However, it may represent the late escape of a small, evolved volume of mantle-derived magma that previously underplated the lower crust and induced partial melting to generate the "infracrustal" I-type granites.

Partial melting of lower continental crust by the intrusion of, or crustal underplating by, mantle-derived mafic magmas has been assigned an important role in granite petrogenesis, based on both field observations in Tasmania (McClenaghan 1984) and elsewhere in the Lachlan Fold Belt (e.g. Soesoo & Nicholls 1999) and on theoretical grounds (e.g. Huppert & Sparks 1988). However the possibility and nature of a mantle-derived chemical component in the granites themselves remains controversial (cf. Collins 1998 *vs* Chappell 1996, Chappell *et al.* 1999, and references therein).

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PAPERS AND PROCEEDINGS OF THE ROYAL SOCIETY OF TASMANIA
VOLUME 135

Contents

page

JAGO, J.B. & BROWN, A.V. — Late Middle Cambrian trilobites from Trial Ridge, southwestern Tasmania 1

KIERNAN, K. — Late Holocene landscape evolution in the Dazzler Range: New evidence 15

BRAY, R.A. & CRIBB, T.H. — *Postlepidapedon quintum* n. sp. (Digenea: Lepocreadiidae) from the bastard trumpeter *Latridopsis forsteri* (Perciformes: Latridae) off the coast of northern Tasmania 21

LOCKHART, S.J. & RITZ, D.A. — Preliminary observations of the feeding periodicity and selectivity of the introduced seastar, *Asterias amurensis* (Lütken), in Tasmania, Australia 25

LOCKHART, S.J. & RITZ, D.A. — Size selectivity and energy maximisation of the introduced seastar, *Asterias amurensis* (Lütken), in Tasmania, Australia 35

WHINAM, J., CHILCOTT, N. & RUDMAN, T. — Impacts of dieback at Pine Lake, Tasmania 41

SHIMELD, P.W. & COLHOUN, E.A. — *Eucalyptus* spp. pollen transport across Liawenee Moor, on the Central Plateau of Tasmania 51

POTTS, B.M., POTTS, W.C. & KANTVILAS, G. — The Miena cider gum, *Eucalyptus gunnii* subsp. *divaricata* (Myrtaceae): a taxon in rapid decline 57

EVERARD, J.L. — Intrusive relationships of granite and dolerite at Lagunta Creek, Freycinet Peninsula 63

Guide for authors 75

1504